PHYSICAL PROCESSES AFFECTING THE LAKE ERIE SHORE IN BAY VILLAGE, OHIO

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INTRODUCTION

In the last few years much attention has been directed toward the resources and interests associated with the Ohio Lake Erie shoreline. The interests occurring along the shore include nearly everything imaginable; residences, industries, ports, recreation facilities and many others. In 1975 the Ohio Department of Natural Resources initiated a program to deal specifically with the concerns of the Lake Erie shoreline in Ohio. Since then, the Coastal Zone Management Program (CZMP) of Ohio has seemingly brought considerable progress toward the promise of wise use of Ohio's coastal resources. The Program has devised an Impact Analysis Matrix to bring a more tangible meaning to the results of land-use studies. There is also much public involvement arising as a result of the Programs efforts. It appears as if Lake Erie's great beauty and usefulness will be preserved in a satisfactory balance if the work of the CZMP can be continued.

There is an important relation between the success of the CZMP objectives and the detailed study of physical processes at all scales occurring along the lake shores and, in turn, the processes behind them.

This presentation attempts to show the influences of several processes on a specific portion of the Lake shore, and also to give a brief insight to the reasons for the occurrence of some of the more important processes. The major manisfestations of this latter objective is in the lengthy section dealing with weather factors as major determinants of shore erosion on the Lake.

It is believed that the combination of macro-and microscale studies, such as this investigation represents, will provide the most useful overview of Lake coastal processes in general. Many details have been neglected for the sake of the time factor imposed upon the project, but it is hoped that this summary may provoke further developement of any ideas herein deemed worthy.

ABSTRACT

The south shore of Lake Erie consists of a variety of environments, ranging from a low cheneer- plain in the west to high bluffs in the Cleveland area. In many instances the bluffs are composed of highly erodible material that encourages varying intensities of shore recession. At the Bay Village study site the beaches are narrow to non-existent in many spots, usually because of updrift structures' interception of much littoral drift supply. The unwise construction of several manmade shore structures throughout the vicinity has contributed to the deficient beach conditions here, and in adjacent areas. The bluffs examined here consist mostly of lake clays, glacial till and occasional beds of limey siltstone averaging a few inches in thickness. Flowage of less indurated material over the face of the bluff tends to conceal many of the lower members of the bluff.

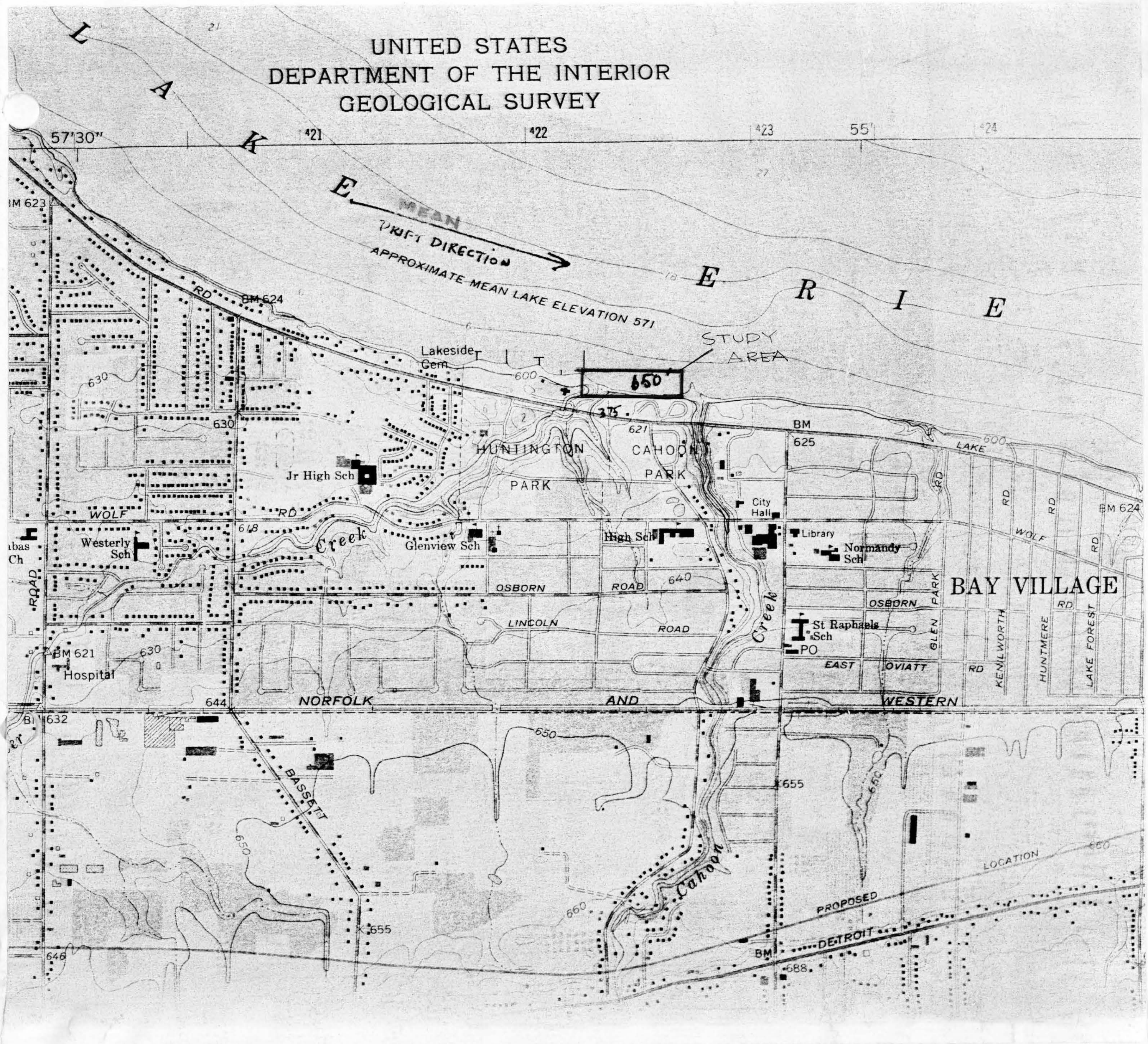

Fig. 1. Location of the Study Area (U.S. G.S., North Olmsted Quadrangle, Ohio)

I. GENERAL PROCESSES OCCURRING ALONG THE LAKE ERIE SHORES

The importance of a specific process or array of processes to the status of a shoreline will be a function of several factors, such as the intensities of the processes, the suceptibility of the shore in question, the frequency of events and perhaps several others. The south shore of Lake Erie may be thought of as an almost infinite number of micro-environments, each having different vulnerabilities to lake processes. A situation of erosion or accretion present at one spot along the shore may be entirely reversed only a few feet away due to angle of wave approach, etc. On the other hand there are some processes such as a general rising of Lake levels which influence these areas in a more widespread manner.

What is presented here is a summarized description of some of the more important lake shore processes and how they are especially related to a south-shore study area under investigation.

A) WATER LEVEL FLUCTATIONS

Water levels on the lake may change over long and very short periods. The changes may be of a local nature or they may affect the entire lake. It will suffice to briefly describe the changes as Short-Term which are generally local, and Long-Term, widespread changes.

1) Short-Term Fluctuations

These brief changes in water level may occur within a few hours and in some cases, minutes. They are generally classified as being Wind tides and Seiches. The wind tide is generated by strong winds occurring across the lake and may "pile up" water several feet above normal average level on a shoreline. The importance of this phenomena to beach and bluff status is immediately obvious when the effect is observed first hand. Plates 1 and 2 are illustrations of wind tide effects. Plate 1 was taken by the author immediately following a heavy wind tide period occurring in the study area, and is a section of the bluff approximately 7 feet above the water level at the time of the photo. The object circled is a small deposit of rounded beach shingle and pebbles lodged on protruding shale members. The same type of material along with dead fish and other detritus was found in the fissure to the left of the hammer. It can be deduced that waves have reached this height on the bluff and perhaps higher. Plate 2 is a collection of yet larger shingles and cobbles found at a lower level than that of Plate 1. This is a dramatic illustration of the magnitude of energy that can be unleashed on a shoreline and the implications possible as far as bluff and beach morphology are concerned.

Seiche action is another form of short-term fluctuation in water levels and unlike a wind tide, it can occur when a strong wind has been predominately offshore. As the wind which initiated the imbalance dies the effect will be

Plate 1 - illustration of the effects of wind tides and seiche action on shore bluffs.

Plate 2 - Beach gravel and shingle left on ledge by high lake levels associated with a wind tide.

sustained by "sloshing" of the lake waters. It should be mentioned that the wind does not have to die in order for a seiche to occur on a leeward shore, the slackening of the wind is only "normal" in the sequence of events. Figure 2 shows the most common seich axes on Lake Erie and their associated periods, as researched by J. Verber (1960).

The importance of these short-term changes to shore processes lies mainly in the fact that when a positive set-up occurs protective beaches are submerged. This in turn means that destructive wave energies will have ready access to otherwise out-of-reach bluffs. Tremendous changes in the lake shore have occurred in extremely short periods as a result of waves riding on the back of a seiche or wind tide. The topic of wind tides and seich generation is discussed in more detail in section II.

2) Long-Term Fluctuations

There are specifically two types of long-term water-level changes; seasonal, and those changes occurring over periods of more than a year, both being closely related to precipitation amounts within the drainage basin.

Figure 3 shows the relationship between monthly precipitation amounts and average water levels occurring on the lake. It should be noted that during the month of lowest water (Febuary) the lake is usually ice-covered near the shore. These two factors combined make this time of year the least active where shore erosion and beach degradation are concerned. There are some exceptions to this however, as will be seen later.

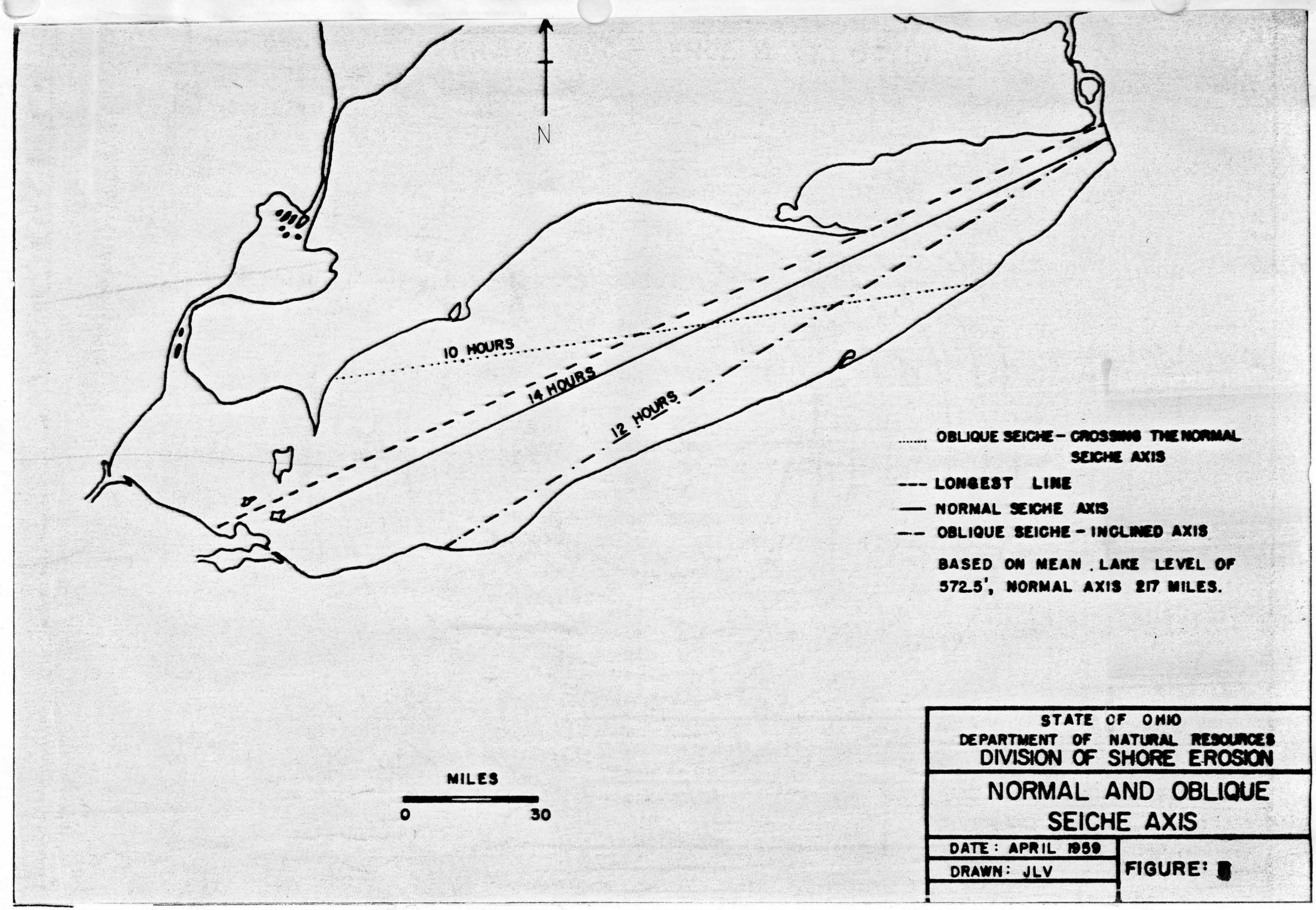

Fig. 2: Common seiche axes for Lake Erie. Other axes are also seen to strike a NW-SE direction. (Ohio Dept. Natural Resources)

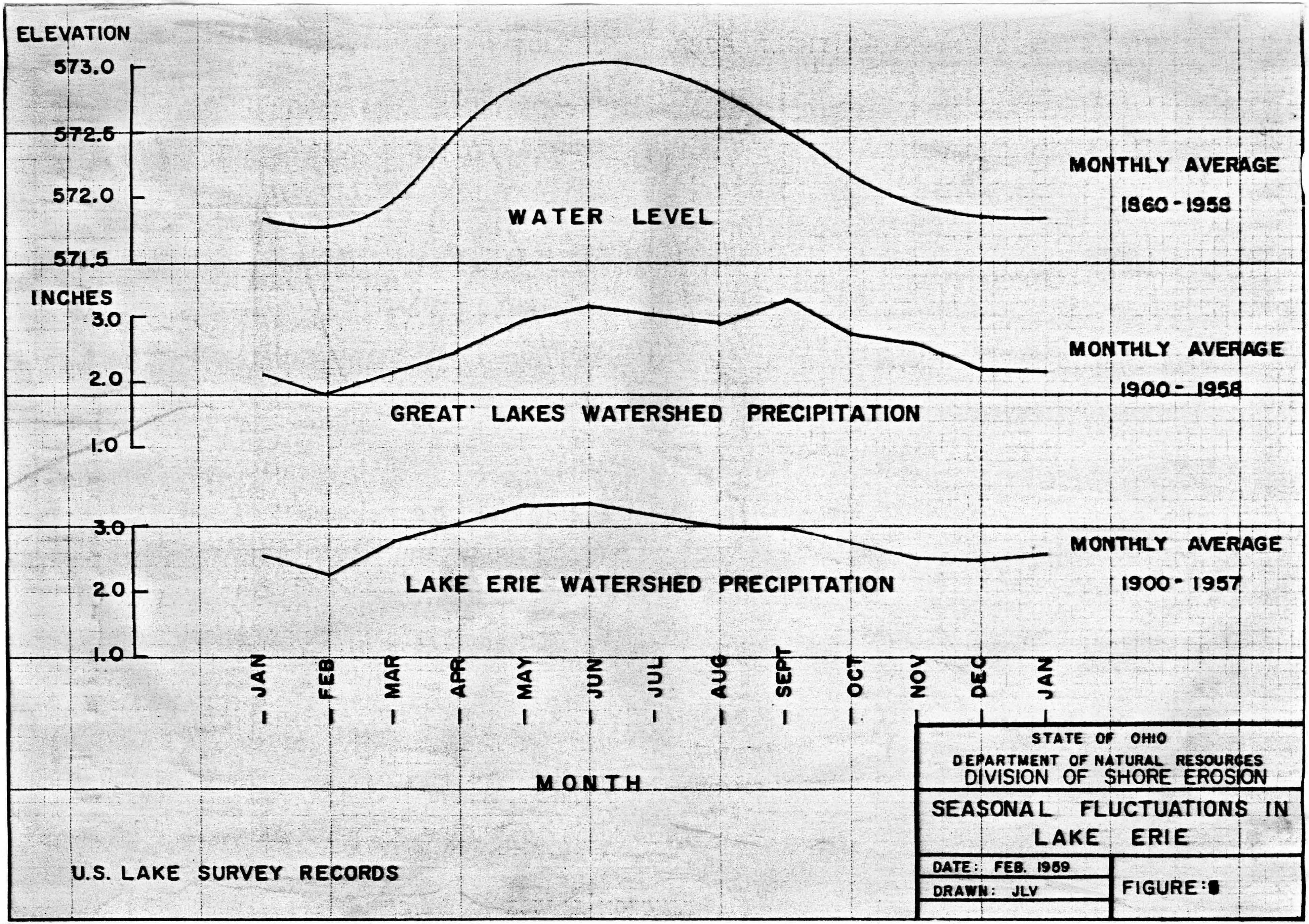

Fig. 3: Regular monthly variations in lake levels are responsible for some Long-Term differences. (Ohio Dept. Natural Resourses)

Over a period of many years there will be a certain amount of fluctuation in precipitation amounts received by the Lake Erie watershed basin. These differences will be reflected in lake levels usually after a time lag of a year or two. Figure 13 on page 34 is a comparson of precipitation of the Lake Erie Basin and water levels of Lake Erie for a period of 16 years. Although long term level differences tend not to be of the magnitude of short term changes, they can be significant to shoreline geomorphology simply because the condition will prevail much longer. Well established vegetation that offers protection to bluffs can endure short periods of submergence, but will be destroyed by an extended period of high water. The causative factors behind long term water level changes are discussed in more detail in section II.

In summation, water level changes are important to the lake shore processes because higher water means possible submergence of protective beaches and hence, a threat of wave erosion to adjacent bluffs. High lake levels also are responsible for some inundation and destruction of manmade protective devices such as groins and revetments.

The effects of short term level changes due to seiches and wind tides are more immediate and more drastic mainly because of the exceedingly high waters allowing wave propagation and strong currents produced by equalization of water levels.

Long term changes are due to monthly and yearly fluctuations in precipitation amounts. A high water level persisting for several years may endanger shore interests primarily because of the submergence of protective vegetation and manmade shore installations. On the other hand, a long period of low water will allow for the restoration of vegetation and wider beaches, as well as the opportunity for the construction of manmade protective structures.

B) WAVE EROSION AND CURRENTS

Waves and currents affecting Lake Erie shores are almost exclusively due to brisk, sustained winds. Strong currents may also be produced as a result of water being channeled through inlets of bays and around headlands in the wake of seiches or wind tide action.

During times of gale force winds from northwest the author has observed waves easily estimated at 10 feet and perhaps higher. Due to the overall shallowness of the lake the larger waves produced tend to break well offshore unless a substantial setup exists. As mentioned earlier, these anomalous "deep water" conditions will allow more wave energy to reach the shore. As the wave plunge points move further up the beach during a storm the beach material and slope talus of adjacent bluffs will either be placed in suspension, or in the case of larger grains, become part of the littoral current bedload.

While wave action is responsible for making material available through dislodging of bluff members or "quarrying" of beaches, the associated currents will transport the materials in a desirable or undesirable fashion from a conservation standpoint. A beach that is frequently disturbed by strong waves and currents will be practically devoid of sand and small-size material, but will consist of larger shingles and cobbles. Refer to plate 3.

Average wind directions and intensities are solely responsible for the waves and most of the currents. Figure 4 is a plot of wind roses for several stations located throughout the Great Lakes region. It is clear that the preponderance of winds occurring in the study area of south to southwest origin for most of the year. This provides for a dominant easterly littoral current on the south shore of Lake Erie near the study area. A brief examination of the aerial photos will attest to the aforementioned drift direction if one notes the accumulation of sand associated with the groin field of Huntington Beach-Park. The particular significance of wave and current energies will be expanded upon in later sections.

C) PROCESSES INDUCED BY MANMADE STRUCTURES

Since the time when the problem of rapid degradation of Lake Erie shores was recognized a considerable number of manmade erosion-retarding structures have been built here. These consist mainly of breakwaters, jetties, revetments, seawalls and groins, with many variations in design found within these structure categories. Whatever the particular structure, its aim is to positively modify a given reach of coastline and to produce a more exploitable piece of property or waterway. However, unless proper planning is employed a carelessly placed structure may prove to elicit more damage than beneficial effects. A very common example of this is seen in the

PLATE 3: A spot on the beach near the western extremity of the study area where frequent wave energies have exposed the siltstone shingle derived from the bluffs appearing in the background.

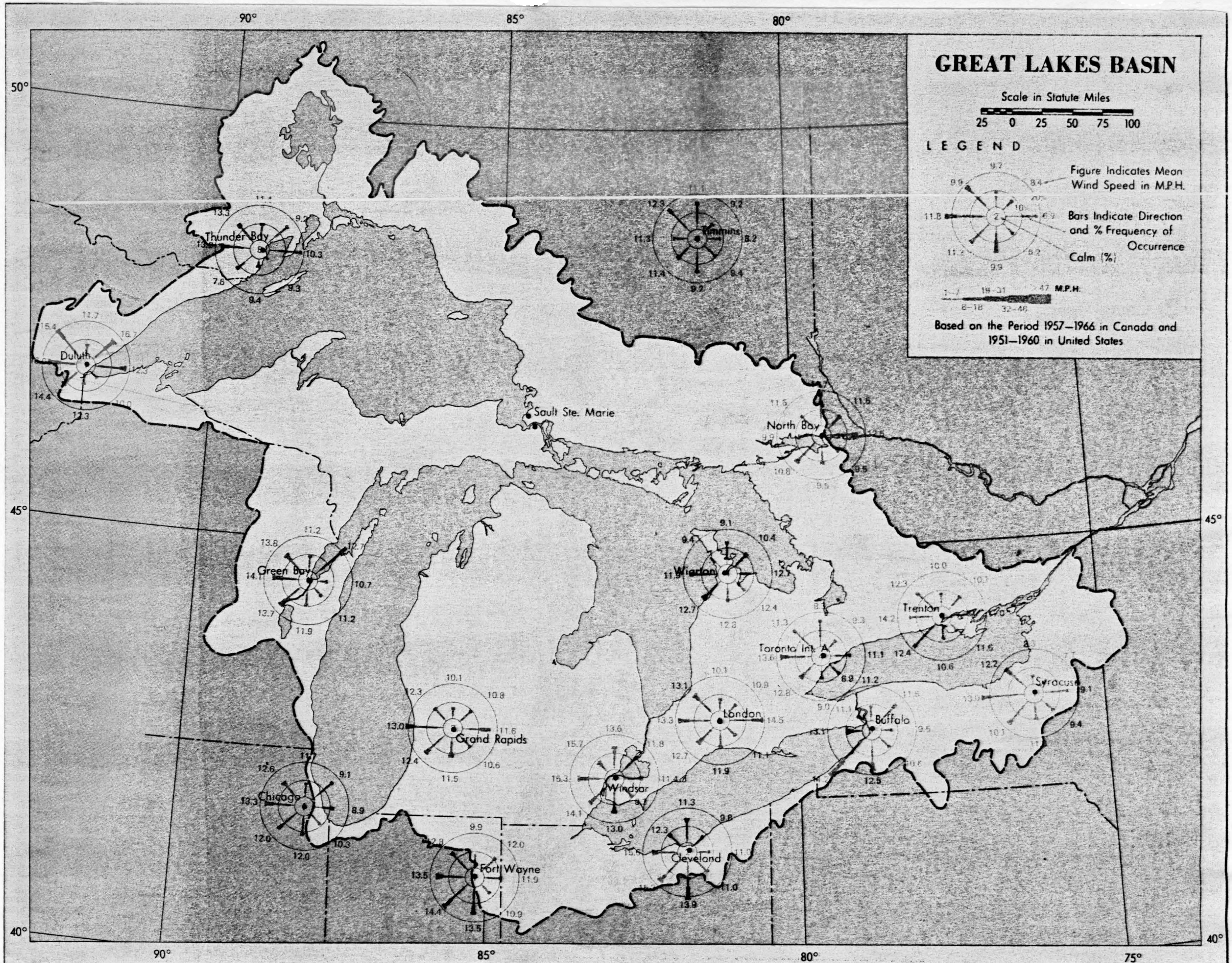

Fig.4: Wind rose diagrams for several stations around the Great Lakes region.(after Phillips and McCulloch, 1972)

down-drift area of a groin field. This area, in the lee of the groin field, with respect to the dominant littoral current, is starved of sand and beach materials because this material is intercepted by the groin field.

This type of situation is found throughout the south shore of Lake Erie and is the topic of several investigations. A particularly useful reference on this matter is found in R. P. Hartely's Effects on Large Structures on the Ohio Shore of Lake Erie (see references cited). As will be seen, this discussion has some direct bearing on the condition of the Bay Village study area, and will be given futher attention (see appendixes A and B).

D) SECONDARY PROCESSES

Storms, waves and wind tides are part of the more spectacular occurrences that produce changes in the Lake Erie shorelines. These dynamic phenomena and their effects are readily observable at any given moment that an area is experiencing them. Perhaps equally important, but less conspicuous are a multitude of more subtle or "secondary" physical processes. Some of these processes were observed by the author during investigations of the Bay Village study area, and are discussed on the following pages.

<u>Aeolian transport of sand</u>: During times of favorable wind velocities quantities of sand and finer-grained material can be blown along Lake Erie beaches allowing for the nourishment or depletion of any given reach of sand beach. Evidence of this movement of sand can be seen in plate 11(page 44), which shows sand and snow intermixed and strewn across the beach by wind. It is worth mentioning that the snow probably inhibits the sand transport greatly and the sand shown in plate 11 was derived from areas of snow-free beach upwind. It is interesting to note that groins constructed for intercepting littoral drift supply are also effective collectors of wind-blown drift. Further ideas concerning aeolian transport are discussed in later sections.

<u>Ice</u>: Due to the long season of freezing/thawing temperatures in the Lake Erie region various processes involving ice become important to the shore zone during the winter months.

The ice coverage of the lake itself is of great import when one considers the large waves that occur when the lake is not frozen. Figure 18 shows the maximum ice coverage of each of the Great Lakes. During the height of a normal winter Lake Erie is nearly completely ice-covered. However, while consolidated ice pack formation is occurring on the lake an interesting side process may be simultaneously inducing changes on the shoreline. The expansion of the ice as it freezes and the effects of large waves arriving from ice-free expanses of water provide the force necessary to produce <u>ice grading</u> and <u>ice push</u>. Ice may effectively move beach materials from place to place with readily observable intensity. It is the opinion of the author that this grading may occur below normal water line on submerged nearshore features. This has not been directly observed, but large mounds of wave-piled ice have been seen to exceed 3 meters in height and to extend as much as 40 meters offshore. Any movement of an ice mass this large must surely effect changes on non-resistant submerged bottom features. Further information on ice work on Lake Erie can be found in chapter 3 of <u>1951 Investigations of Lake Erie Shore Erosion</u> by Howard J. Pincus and Curtis C. Humphris.

Ice formed from ground water and runoff is responsible for ice-wedging and other types of mechanical and chemical weathering affecting Lake Erie shore bluffs. Plates 4 and 5 show portions of the study area bluff during February of 1979. It is fairly evident from these photos that not only is considerable ice present on the face of the bluff, but that removal of bluff material occurs in quite some volume even in the dead of winter (note the material scattered at the base of the bluff). Another interesting observation in conjunction with ice work is shown in plate 6. A small channel dug in the snow at the base of the bluffs reveals alternating layers of fine bluff talus and snow. This may indicate the occurrence of one or two specific sequences of events. The layering may be due to a period of thawing temperatures, allowing solifluction to produce the scree, then colder temperatures and snowfall bury the talus and the cycle repeats. An alternate explanation is that the talus is buried by blowing snow rather than a period of precipitation being solely responsible. It is not known how continuous the influx of slope scree is with respect to weather changes, and the subject certainly lends itself to futher investigation.

Plate 4

Plates 4 and 5: Ground water and runoff form ice that has a significant effect on bluff-face degradation. Note the scree that has accumulated at the base of the bluff in Plate 5.

Plate 5

PLATE 6

Plate 6: A small channel excavated in the snow at the base of the bluff reveals alternating layers of snow and debris derived from the face of the bluff. The rate of wastage of the bluff may bee fairly constant with intermittant periods of snow being responsible for the layering.

Another possiblity is that the layering reflects a change of rate of wastage because of varying weather conditions.

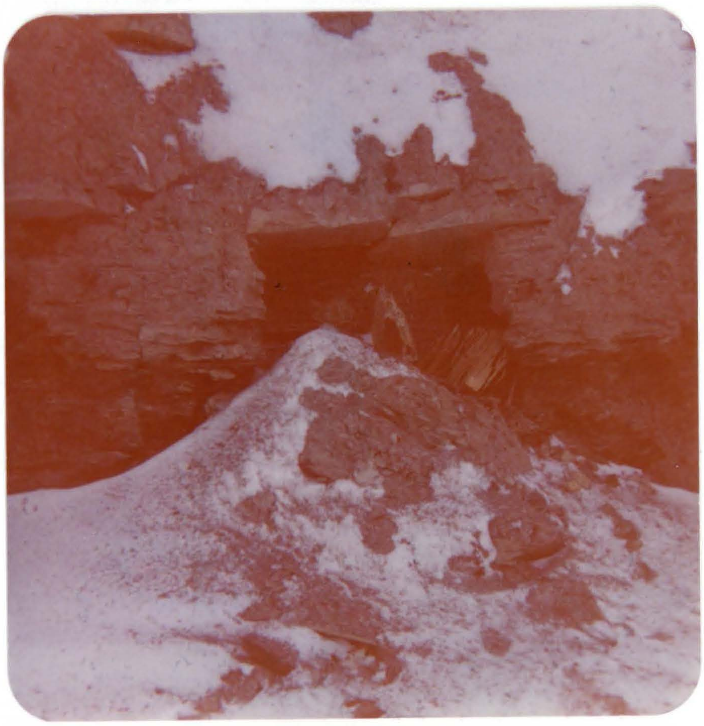

PLATE 7

Plate 7: Another form of wasting is shown here; a series of joints in the more consolidated material may allow water and other weathering agents to cause failure of larger blocks.

Water that has infiltrated jointed, consolidated bluff members may, by way of frost-wedging, dislodge larger blocks of material such as shown in plate 7. In times of temperatures remaining above freezing the same ground water can weaken the bluffs by sapping and spring action. Plate 8 shows evidence of the presence of a frozen spring at the eastern extremity of the study area. Further evidence of the work of ground water is seen in plate 9. The material flowing down the bluff slope originates from the upper portion of the bluff that was fairly well-saturated with water at the time the photo was taken. It seems that the ground water is present at all levels on the study area bluffs and that this accounts for much of the degradation impetus.

The preceding discussions are only a brief look at the less conspicuous physical processes occurring along the lake shore and should command a more rigorous treatment in any further investigations of this area.

E) METEOROLOGICAL INFLUENCES

All the processes discussed thus far have varying degrees of impact upon the condition of the lake shore. What is left to be shown is that all the operations,large and small, are brought about by the periodic changes in the atmospheric environment engulfing the contingent coastal regions. It is the purpose of the following section to exemplify relationships between the atmosphere and the coastal zones of Lake Erie, particularly where the problem of shoreline recession is concerned.

PLATE 8

Plate 8: Frozen springs are illustrative of the importance of ground water to bluff degradation.

PLATE 9

Plate 9: Material from the top of the bluff is washed down the face of the bluff where it may be removed from the site by waves during storm times.

The material seen flowing down the slope here is a mixture of glacial till and lake-clays.

II. WEATHER FACTORS AS BASIC DETERMINANTS OF LAKE ERIE SHORE EROSION

INTERRELATION OF EROSION DETERMINANTS

It is common practice for the authors of various texts on elementary meteorology to include an energy-flow schematic for the heat budget of the atmosphere. These diagrams illustrate several means of dispersion of incoming solar energy and how the energy is allocated to the dynamic mechanisms of the atmosphere,ocean and land. If these relationships are examined in greater detail or with a more refined focus in certain areas parallel systems will emerge that may yield greater insight to less conspicuous environmental processes. Such a parallel system can be contrived for a land-water energy zone as related to the product of erosion. Illustrated in figure 5 is an example of relationships that can be seen between the air-lake interface and coastal erosion. Although this diagram is somewhat simplified and no magnitudes are given, a general understanding can be gained of the flow of the energy responsible for shore erosion. The diagram presented here is constructed particularly for the Great Lakes and other inland bodies of water, of comparable size and characteristics. If the oceans considered in the construction of this chart several additional factors which are not found in the Lakes would need to be incorporated into the scheme such as tidal, fluvial and biological influences. The following diagram and explanation are elementary, but they underline the important basic elements that can be traced as energies supplied for shoreline erosion.

It is well-known that the sun is the primary source of momentum for weather phenomena. However, due to differences in angles of incidence of solar radiation on the surface of the earth, seasonal influences, etc., the sun does not impart a uniform amount of energy per unit area over the entire sunlit portion of the globe. Also, land masses have a lesser specific heat than the oceans. These differences and others induced by geographic features are responsible for marked contrasts in the overlying atmosphere around the earth. It can easily be deduced from the diagram of figure 5 that without significant solar energy input the processes of erosion might be reduced to nil. This may offer some interesting implications with regard to other planets receiving more or less insolation than Earth.

A particular volume of air will tend to assimilate the thermal characteristics of the land or ocean mass that lies beneath it, provided the air remains relatively stationary for a sufficient period of time. These large volumes of air are the AIR MASSES that are directly responsible for the weather in a given area. See figure 6. The contrasts between two adjacent air masses' thermal or humidity characteristics may produce areas of instability at their points of coincidence. These bordering lines of activity are the FRONTS which sweep across the middle-latitudes. There also exists a major boundary between air masses in the upper middle-latitudes called the POLAR FRONT which generally separates the polar and subtropical air masses. Winds in the polar regions are predominantly easterly in flow while on the south side of the polar front the Prevailing Westerlies dominates the air-flow. See figure 7.

As the polar front fluctuates back and forth over the mid-latitudes the opposing winds on either side of the front will frequently cause an irregularity or wave to develope along the front. Warm air is then nudged toward higher latitudes while cold air invades from behind. With all the movements of air taking place the Coriolis "force" organizes this random circulation into the generation of a WAVE CYCLONE or EXTRATROPICAL LOW, the chief producer of wind, precipitation, and temperature and pressure variation in the middle-latitudes. It is important to remember that the Great Lakes region is in the middle-latitudes and lies in the paths of a great number of these storms each year. In figure 8 several common storm tracks are shown. Note the number of paths crossing or falling

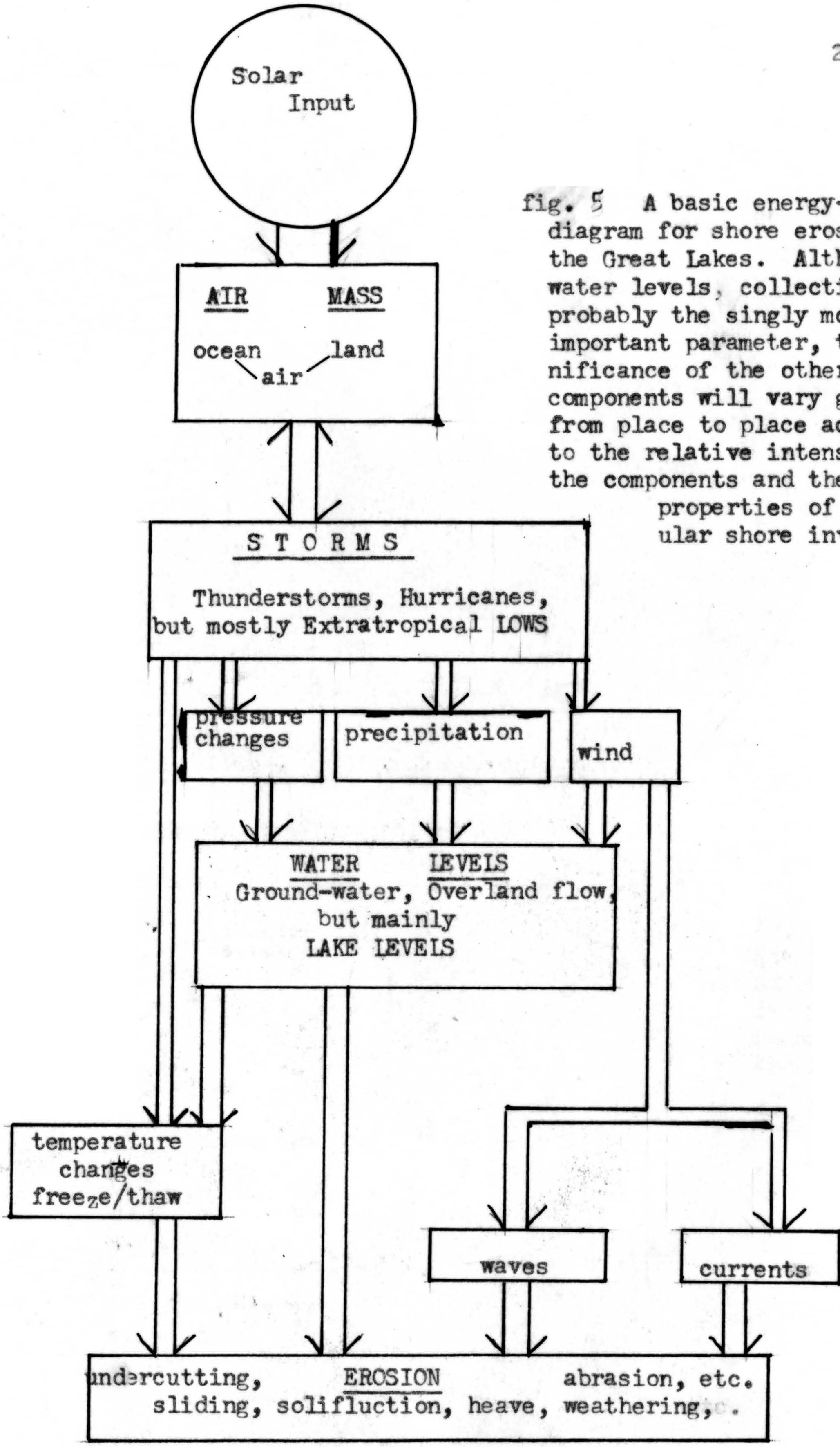

fig. 5 A basic energy- flow diagram for shore erosion on the Great Lakes. Although water levels, collectively is probably the singly most important parameter, the significance of the other components will vary greatly from place to place according to the relative intensities of the components and the inherent properties of the particular shore involved.

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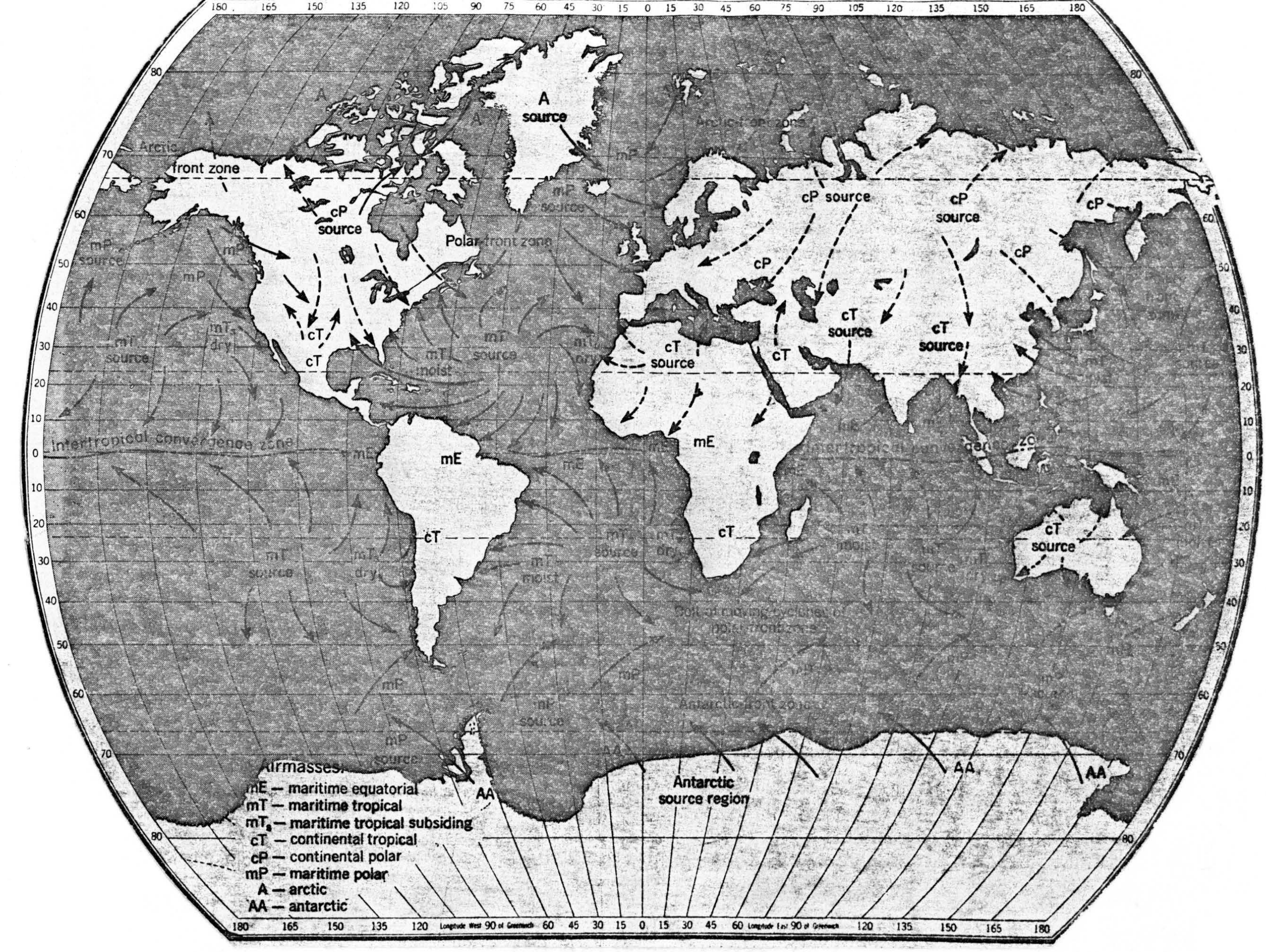

fig.6 after Critchfield, 1974

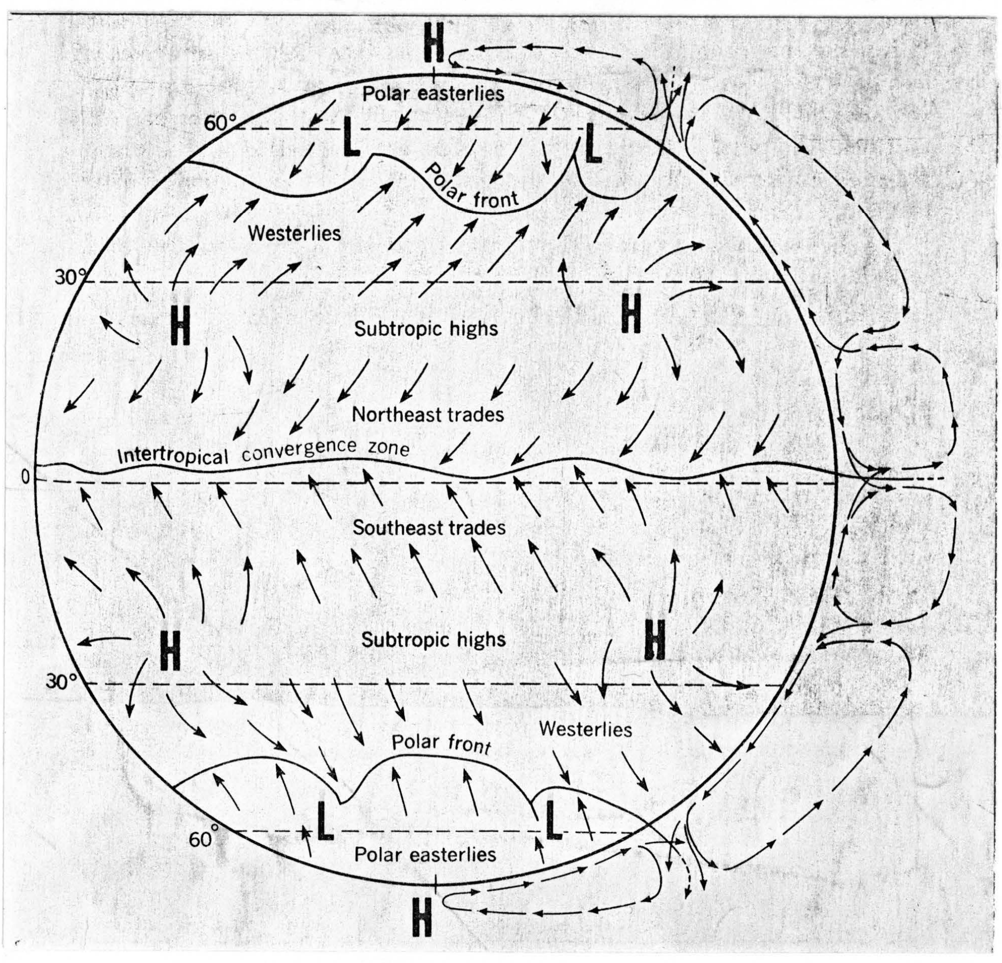

Fig. 7: The average positions of frontal features and associated wind patterns (after Critchfield, 1974)

quite close to the Great Lakes region, particularly Lake Erie.

As these storms advance across an area they produce four main effects: wind, precipitation, temperature changes and pressure variations, as illustrated in the diagram of figure 5. When a cyclone passes over or near a body of water such as Lake Erie certain conditions are set-up that will promote shore erosion. Due to the significance of extratropical disturbances as producers of erosion the specific nature of the storms and the relationships between storm properties and erosion will be presented in later sections.

Although the behavior of the polar front

Although the behavior of the polar front and the extratropical cyclones produced by it account for the majority of the disturbances over the Great Lakes, there are other less important phenomena ultimately responsible for erosion, namely; THUNDERSTORMS and the infrequent influences of TROPICAL STORMS (HURRICANES).

Thunderstorms occur over the Great Lakes region mainly during the months of June, July and August as indicated in figure 9. Thunderstorms occurring during other times of the year are insignificant compared to those of the summer months. There are predominantly two types of thunderstorms that occur frequently over Lake Erie; AIR-MASS THUNDERSTORMS and those associated with advancing frontal systems (FRONTAL THUNDERSTORMS). The air-mass type commonly developes over greatly heated land areas adjacent to the Lake and may progess over the Lake in various directions depending on air flows at upper levels in the troposphere.

Frontal thunderstorms are produced by the familiar unstable conditions contiguous to a front and may be intensified by the frontal passage over the Lake. The author has been witness to such an occurrence in which instabilities present not only produced heavy thunderstorms, but a considerable number of waterspouts were seen throuhgout the area.

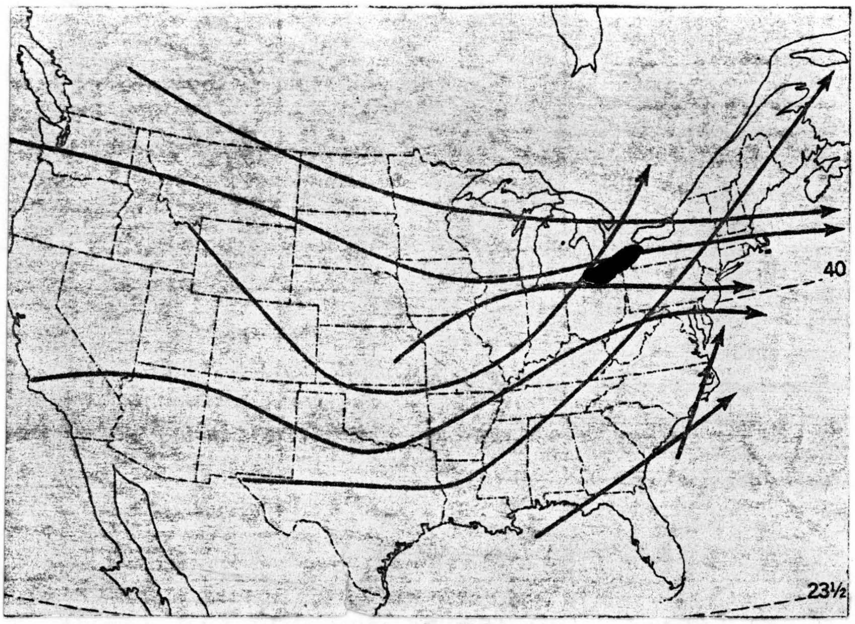

fig. 8 common paths of extra-tropical storms across the U.S. (after Critchfield, 1974).

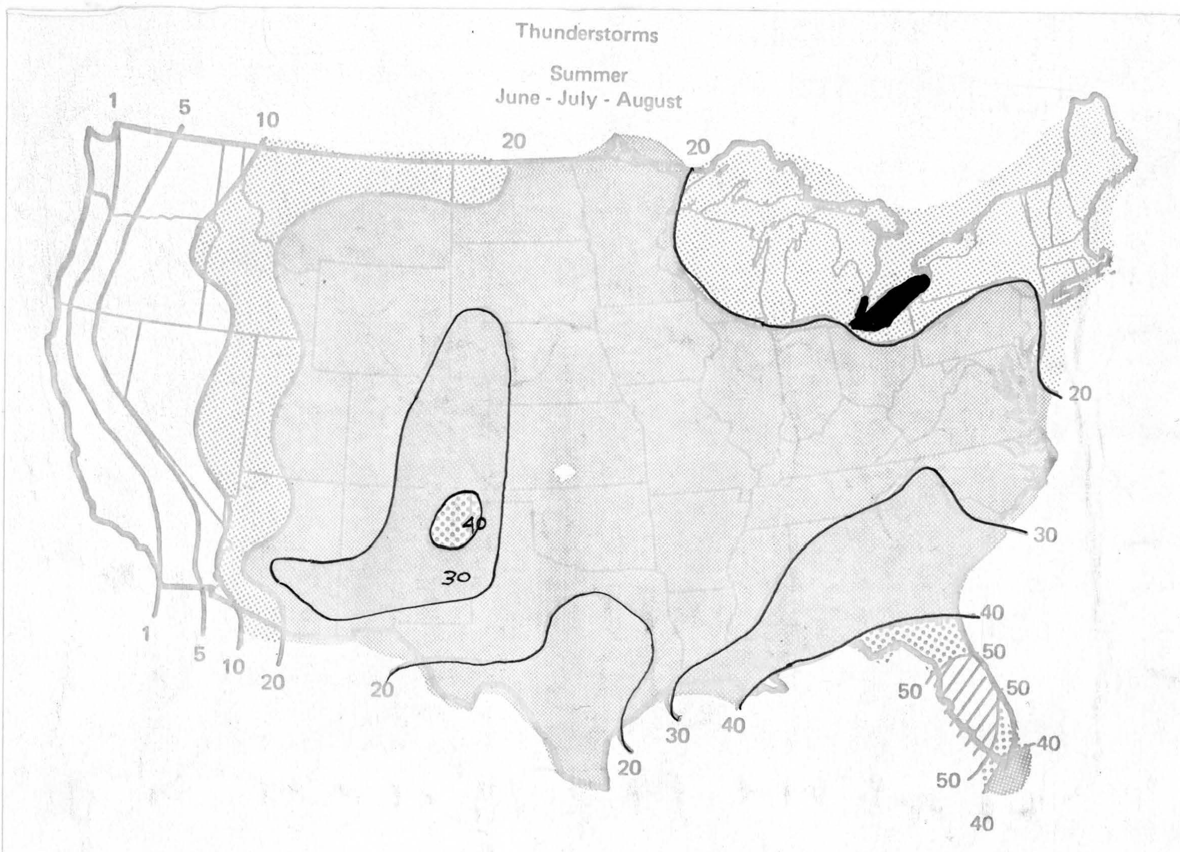

fig. 9 Distribution of summer thunderstorms (Chief of Naval Operations, 1973).

The formation of this particular storm was due to the invasion of cold air from behind the front over an extremely warm lake (74°F), and hence,a rapid increase in moisture and lapse rate within the invading air mass. This type of unstable condition may occur in late summer and fall over Lake Erie. Plate 10 is a photograph of an advancing thunderstorm produced by the aforementioned frontal conditions. The photo was taken in late summer by the author at the site of the shore-study area. The swell produced by this particular storm was about 3 to 4 feet in height and had a duration of about 2 hours(Note the white breaker lines in the photo).

The importance in recognizing these storms as potential producers of significant erosion conditions arises from the severe nature of the winds of a thundrstorm cell. The initial downdrafts of the cell leading to the first gusts of wind preceding the storm may exceed 100 knots in extreme cases. Although these winds are relatively short-lived they may generate waves and surges capable of much shoreline havoc in areas in line with the storms advance. Figure 10 gives an idea of the winds associated with a thunderstorm and how they might initiate waves in the direction of movement of the storm. It is not suggestive that thunderstorms account for a great portion of shoreline degradation, but it is sufficient to point-out that the catastrophic events occasionally associated with these storms may produce extreme changes in isolated areas. A representative example of this is cited in "The Lake Erie Independence Day Storm of 1969", found in the Mariners Weather Log (13(5): 203-204).

Plate 10 Photo of a thunderstorm approaching the south shore of Lake Erie. The storm was caused by cold air advancing over an extremely warm lake. (photo Barnett, 1976).

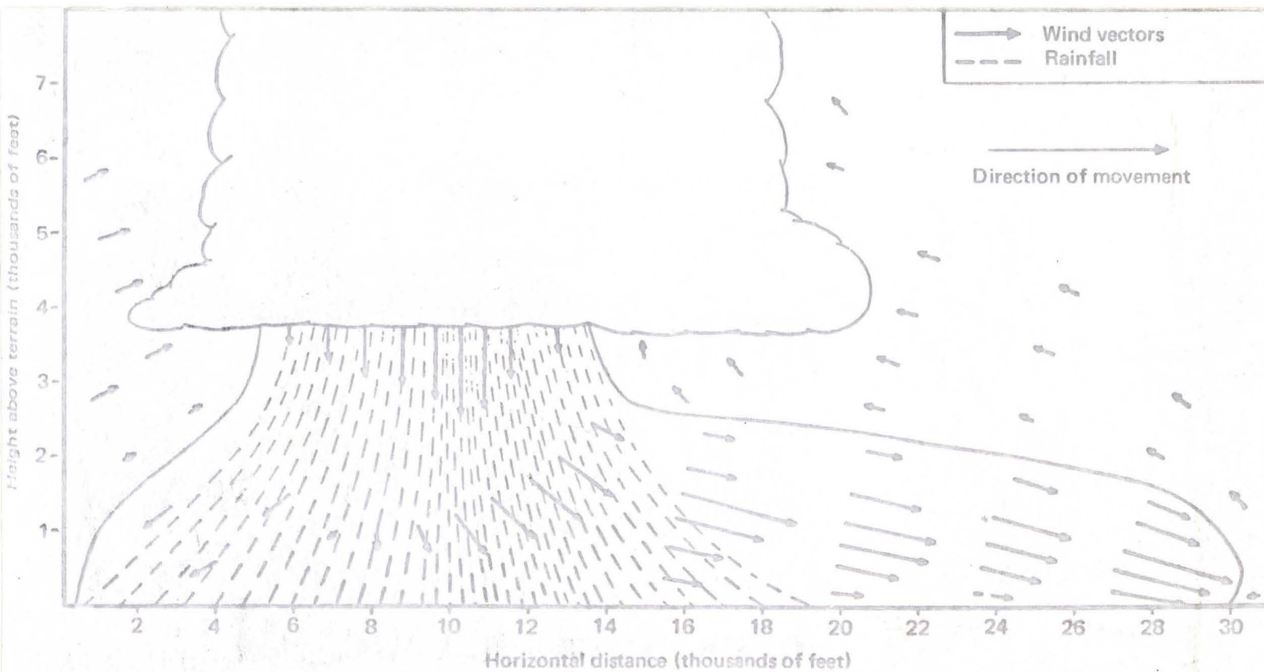

fig. 10 Cross-section of wind pattern associated with a mature thunderstorm cell (Chief of Naval Operations,1973).

FOUR INDIVIDUAL FACTORS RELATED TO LAKE SHORE EROSION

As storms of various types and intensities migrate across the Lake Erie region they will impart a multitude of dynamic effects to the water and shoreline of the Lake. Among the most obvious and important of these factors are four major properties of storms; PRECIPITATION, WIND, TEMPERATURE CHANGE and PRESSURE FLUCTUATIONS. It is difficult to assign an order of importance to these factors since varying intensities will be determined by the characteristics of any given storm. It Although it may be concluded that pressure fluctuations are normally not of the magnitude as to be a major producer of disturbances on the Lake, there are some isolated instances in which this is not true.

PRECIPITATION: LONG TERM EFFECTS

Rainfall, snow, sleet and any other sort of precipitation occurring over the Lake Erie drainage basin will ultimately be handled by the environment four general ways. The water may be incorporated into the plant life of the area if the time of year and other conditions are right as it soaks into the ground. If the water is not intercepted by plants it may be evaporated back into the air or it may contribute to the water table below ground surface. The remaining water which does not enter one of these reservoirs will occur as overland flow or runoff. Figure 12 shows the approximate boundaries of the Lake Erie drainage basin. Precipitation occurring within this boundary over a period of time will ultimately be reflected in the water levels of Lake Erie.

It should be mentioned that Lake levels are not usually responsive to short term wet or dry "spells" , but require a precipitation deficit or surplus that has been established over a period of a few years or more. Figure 13 is a comparison of recorded precipitation amounts and water levels for Lake Erie. Most noticable is the above average precipitation of the late 1940's and the subsequent higher lake levels of the early 1950's.

It can be recognized that the high precipitation amounts culminating in 1950 were followed about two years later by correspondingly high lake levels. Interestingly, another such lag in responses was discovered by Collinson and Berg (1976) in their studies on Lake Michigan shore erosion. They recognized an approximate four-year lag between high lake levels and the onset of a period of marked shore recession and erosion.

Combining the observations outlined above one might be tempted to say that higher erosion rates would probably follow six years after a peak precipitation period. This may turn out to be nearly so, but other factors should be evaluated before any conclusions can be drawn, such as the nature of affected Lake Erie shores compared to those of Lake Michigan.

The significance of high water levels in Lake Erie has different implications depending on who you are. Shipping firms concerned with the amount of cargo they can transport will gain advantages from a higher water level that allows a greater draft on their vessels. Lake Shore residents however, will suffer loss of property with the onset of high water as a function of shore materials. Once a protective beach is submerged, wave and current energies may work directly on exposed non-resistant bluffs.

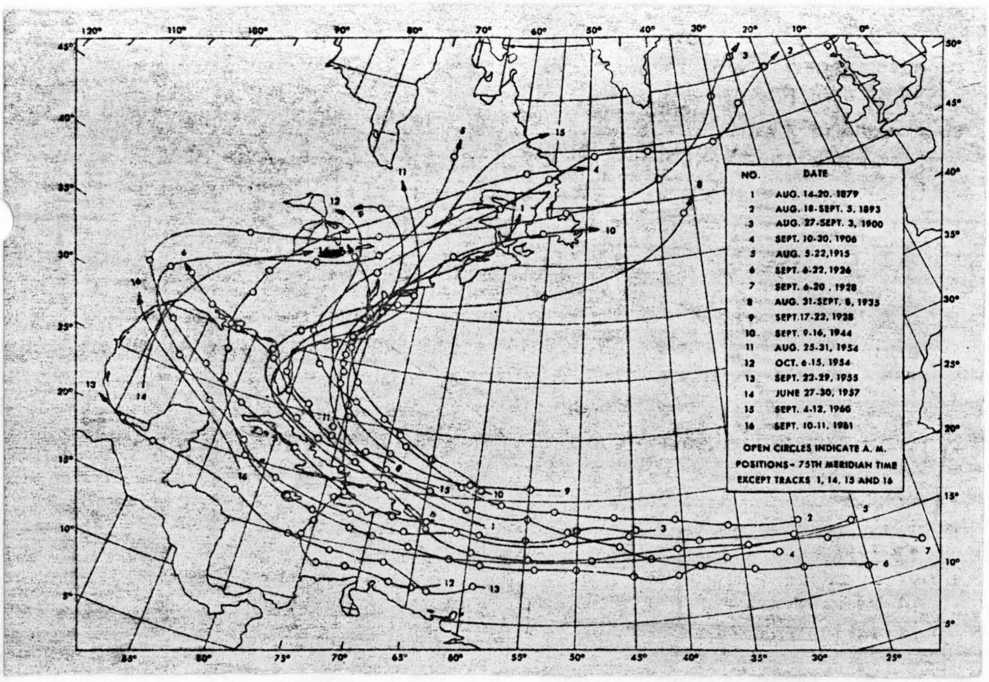

fig. 11 Tracks of part-icularly severe tropical storms over the past 100 years (after Critchfield, 1974).

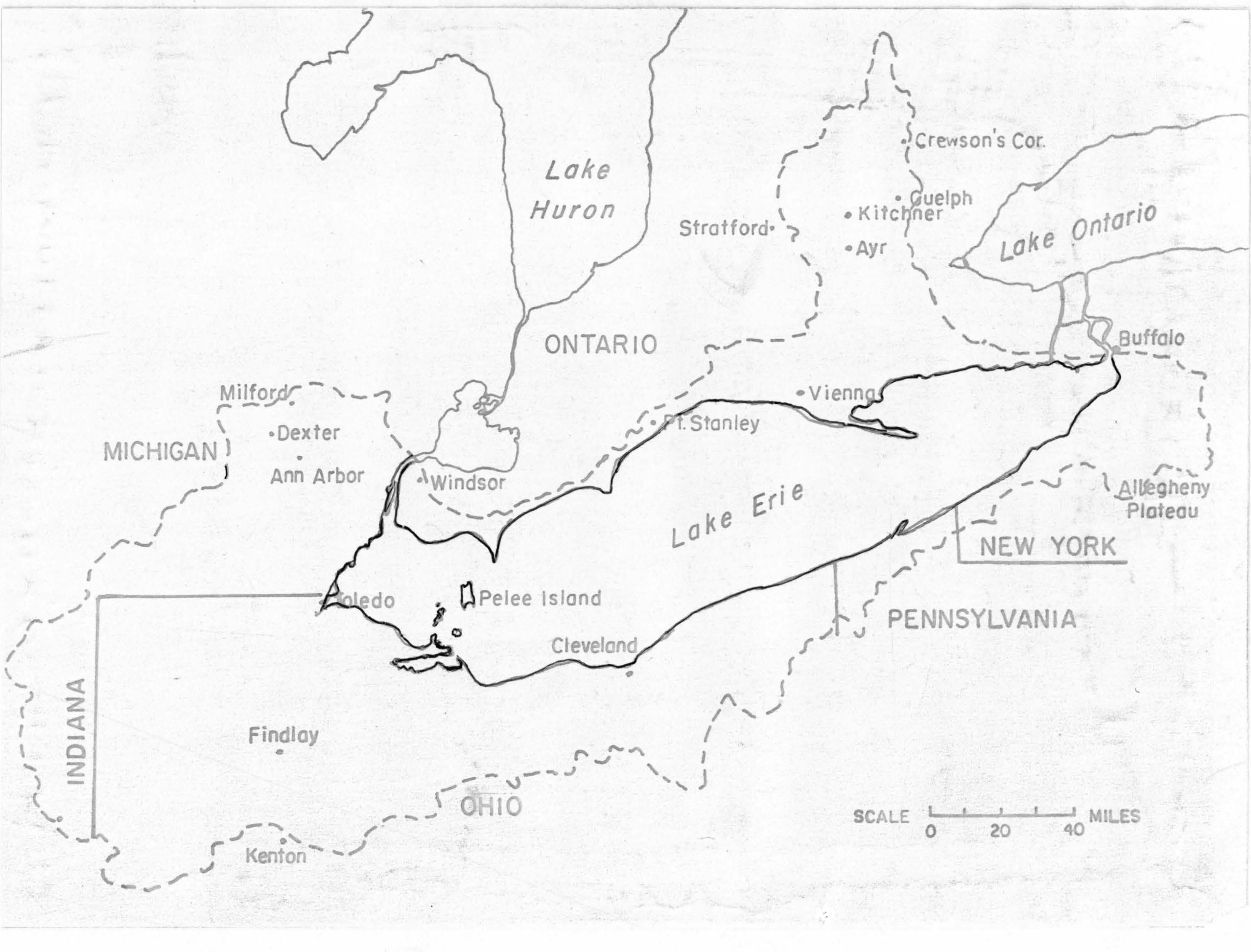

fig. 12 The Lake Erie drainage basin (dotted line) (after Sanderson, 1966)

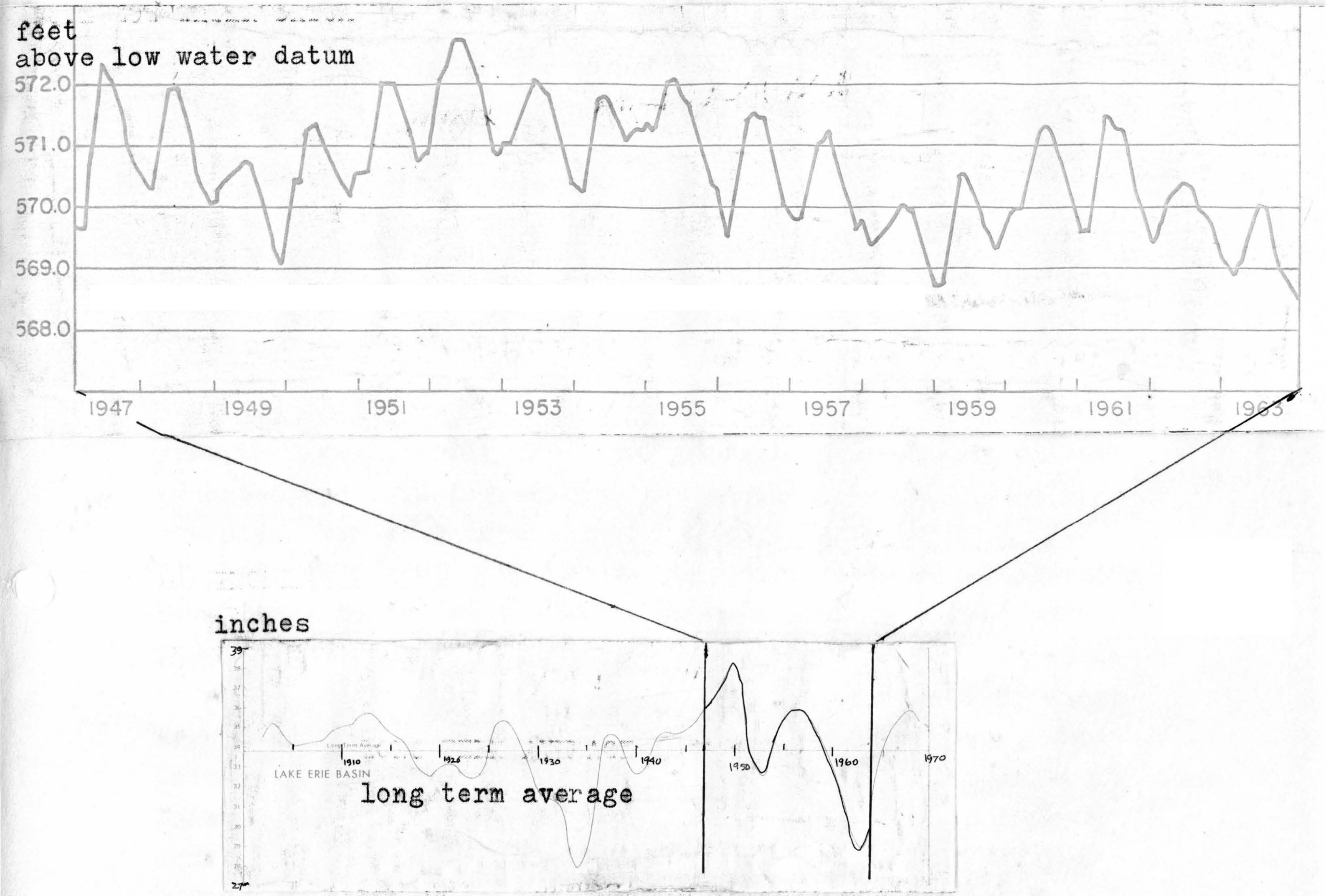

Figure 13: A comparison of past rainfall amounts in the Lake Erie basin and lake water levels. The top portion of the figure was taken from Marie Sanderson(1966), the bottom from Phillips and McCulloch (1972).

The long range amounts of precipitation that are a large factor in amounts of shore erosion on Lake Erie are collected and tabulated by various climatological stations scattered throughout the U.S. and Canada within the lake basin perimeter. This means of collection and recording provide a reasonably accurate representation of precipitation amounts for any given period over LAND areas of the basin.

QUANTITATIVE ASSESSMENT PROBLEMS

One annoying fact remains however, that Lake Erie itself occupies about 30% of its own basin. This, along with the fact that there are no precipitation gauging stations over the Lake account for a considerable discrepancy in recorded and actual precipitation amounts for the basin as a whole. Marie Sanderson in A CLIMATIC WATER BALANCE OF THE LAKE ERIE BASIN (1966) remarks: "Over water precipitation is a large factor in the water balance since one inch over the surface of the lake is equivalent to 8,600 cfs per month in the flow of the Niagara river. At the present time there are no systematic records of over water precipitation. Many theories have been formulated comcerning the relationship of lake to perimeter precipitation but results are far from conclusive." Phillips and McCulloch in THE CLIMATE OF THE GREAT LAKES BASIN, (1972), state; " Whether more or less precipitation falls directly on the lake as compared to the land basin is a matter of controversy among researchers studying over-lake precipitation. This is a most important matter since over-lake precipitation represents a large and immediate supply of water to the Great Lakes system." And further states concerning estimates; "There is little agreement either in the size and magnitude of the difference or in their seasonal variations." Many now recognize the problem presented here and some workers have developed some promising methods of measuring rainfall intensity over inacccessible areas. T.A. Seliga and V.N. Bringi (The Ohio State University,1978) have presented methods whereby rainfall intensities may be measured by non-attenuating wavelength radar. If successful such methods may ultimately prove valuable in prediction of lake levels where data are tabulated for an extended period of time.

PRECIPITATION: SHORT TERM EFFECTS

Ground Water Levels

The strength of materials constituting a slope or bluff such as those bordering many Lake Erie shores, is exceedingly dependent on the amount of water that occupies the interstitial areas of the regolith. As pore pressure is increased and a hydrostatic head is established above and within bluff materials they become more susceptible to failure by solifluction, flow, slides and other forms of mass wasting. An increased amount of groundwater may also cause an increase in bouyancy of the slope material, and hence, reduce frictional forces and overall shear strength of the bluff. The situation may be quite different in areas where bluffs are composed mainly of bedrock and are not similarly responsive to groundwater dynamics. However, the study area under examination here is not composed of well-consolidated materials for the most part,and under favorable conditions shows responses to sudden influxes of water. Ground water may also increase the degree or amount of weathering on otherwise fairly stable rock structures allowing more hydration, disintigration and subsequent lowering shear strength. It should be clear at this point that a period of intense rainfall or influx of meltwater will be directly reflected in the degree of mass wasting of a particular susceptible slope. It should be mentioned, that the degree of susceptibility will also be dependent on the composition, fragment size and compaction of the material involved.

Subaerial Water Flow

Rainfall or meltwater that does not inflitrate the soil or regolith of an area is considered to be runoff and may have a great deal of erosional power. During times of light rain or gradual melting in the water capacity of the ground is not rapidly exceeded and surface flow of water will be restricted somewhat. However, there can exist conditions in which rapid, turbulent runoff will contribute to more degradation of a bluff than any of the other factors in a storm or energy change situation. Heavy thunderstorms with large and sudden amounts of rain will cause over land flow and rill formation in a matter of minutes on poorly consolidated bluff materials. The area may have previously been bone dry, but a sudden influx of water surpasses the rate at which the ground materials can be infiltrated. Magnifying this effect on Lake Erie bluffs is the steep grade of the slope itself which will allow the flowing water to generate even more eroding potential.

Prolonged periods of rain such as those associated with stationary fronts or large, slow-moving storm systems may also be to blame for overtaxing subsurface water capacity which will be reflected in increase subaerial flow. In such a case bluff materials may first be weakened by increased interstitial water and pore pressure, then eroded even more easily because of lessened cohesional and frictional forces. It should be noted that most clay-rich soils will maintain much of their cohesive nature even in the presence of water, and that these soil types may offer some resistance to the processes discussed above. The bluffs of the Bay Village study area contain much of this clay-bound material and it is possible that this property has helped preserve the bluffs somewhat.

Another more unusual situation is that found in early spring or winter when snow blankets a frozen soil and the area experiences a melt coupled with a substantial rainfall. The frozen ground cannot be infiltrated by the abrupt, voluminous amounts of water. Warmer air temperatures will compound this situation by further melting of the snow from the top. The result of all this is an extreme rate of runoff that may be quite effective in washing away unprotected slope materials.

RAIN SPLASH

Moderate or heavy rain driven by strong, persistent winds is a definite energy source for the direct erosion of a non-resistant bluff slope. Rainsplash has recently been examined by many as a possible major factor in the degradation of erodible surfaces. Figure 14 illustrates the effects wind-driven rain may have on a steep slope like that of the Bay Village bluffs. According to Ritter (1978) there are 3

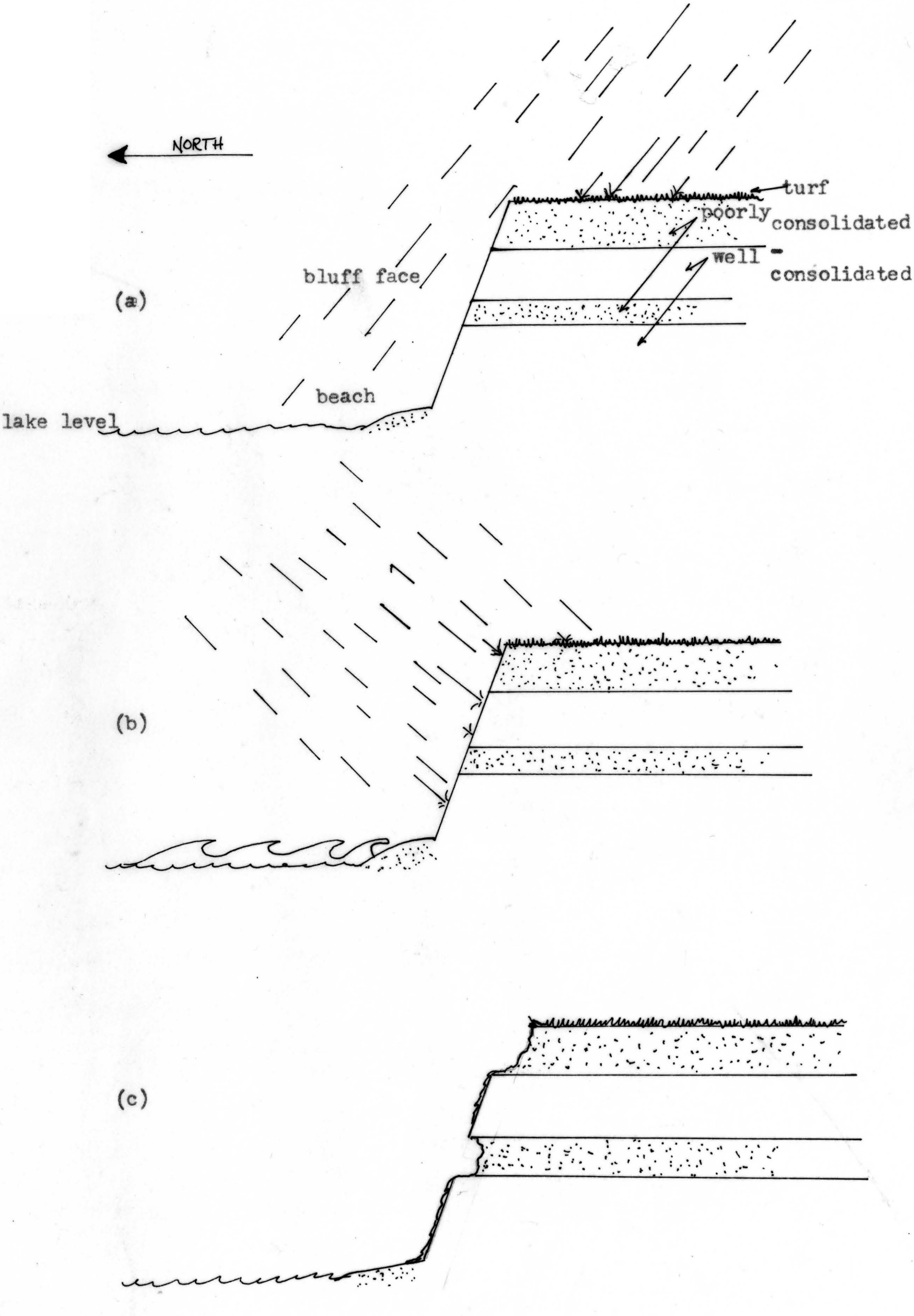

fig. 14

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principle determinants of rain splash erosion magnitude; the kinetic energy of the rain drops, the type of soil exposed, and the steepness of the slope. Ritter also presents an equation to deal with Average Annual Soil Loss, thus:

$$A=RK(LS)CP \qquad \text{(after Ritter, 1978)}$$

Where A equals Average Annual Soil Loss, R equals rainfall, K equals erodibility, LS equals the Slope-Length steepness factor, C equals a cropping management factor and P equals the conservation factor. Note that the direction and intensity of the wind will determine how effective the raindrops will be in eroding the bluff and that both direction and intensity will be determined by the nature and proximity of the atmospheric disturbance. Considering the Bay Village bluffs, part "a" of figure 14 shows that a south-driven rain will not be directly incident on the face of the bluffs, providing they are of sufficiently steep repose, and thus not be particularly effective in eroding the bluff face. On the other hand, a steady, wind driven rain from the north can readily remove any loose material as illustrated in parts "b" and "c" of figure 14. Not only is the softer material removed but shear stress may be increased in overhanging blocks of lithified bluff members.

SNOWFALL

Not much investigation has been done concerning snowfalls effect on eroding bluffs, but some basic understandings may be suspect for analysis; heavier snow cover is known to preserve underlying soil temperatures; snow is a temporary storage of water for the environment that may be liberated as a function of several factors, such as air and ground temperatures and insolation.

WIND

Sustained high winds on Lake Erie are responsible for more shoreline erosion and bluff retreat than any other single factor. Shallowness and other characteristics of the Lake Erie basin allow the waters to respond more dynamically to winds than the other Great Lakes. Winds can drastically effect local water levels by producing wind tides and seiches. These phenomena, in turn, will provide a more suitable set-up "base" for large waves to travel further shoreward before breaking and hence, present a magnified threat to shore installations and bluffs.

Some work has been done concerning seiches, wind tides and waves on Lake Erie in particular. James L. Verber (1959) forwarded a relationship called Merian's Formula which relates the period of a seiche to gravity and the characteristics of the containment basin;

$$T=2L/gh \qquad \text{(after Verber, 1959)}$$

where T is the period, L is the length of the basin in feet, g equals $32.16 ft./sec^2$, and h is the depth of the basin. Verber divided Lake Erie into 3 individual basins where operation of the relationship could be readily observed, but he acknowledges that many seiche node axes are possible depending on prevailing meteorological conditions.

Seiche and wind tide are significant to erosion due to the fact that waves of destructive size will travel further shoreward to normally undisturbed property expending their energies there rather than offshore, as would be the case during lower water level times.

On Lake Erie seiches may be considered to be the residual or secondary ocsillations of a wind tide. Fairly extensive research on Lake Erie wind tides was done by George W. Platzman (1965), which resulted in reasonalbly accurate methods for predicting magnitudes of wind tides generated by winds associated with antecedent storms. Among other findings, Platzman discovered that storms most likely to produce significant positive of negative set-up conditions at opposite ends of the lake (SW and NE) were those storms tracking to the NW of the Lake and roughly parallel to its long axis.(see fig. 15) Platzman could not find any definite relationships between magnitude of set-up and the source region of the storm. However, he did present an interesting relationship between wind tide height and effective wind square, as shown in figure 16. Differences in water levels of as much as 15 feet have been occasionally observed between Toledo and Buffalo during periods of maximum wind tide.

Wind tides and seiches can produce high water conditions which may expose to the water level structures and bluffs vulnerable to even minor agitation, to say nothing of waves that have been known to reach 14 feet or more on Lake Erie.

A factor overlooked for the most part, is the effect of wind on the sand beaches of the Lake. Although it may seem a relatively minor mode of transport, considerable quantities of of sand are moved along the wider, more exposed beaches. Plate 11 shows sand intermixed with blown and drifted snow at the site of the study area, indicating that even during times of frozen soils sand may be transported by brisk winds. Sand grains and larger ice particles during saltation along the beach may dislodge more grains otherwise frozen in place, thus adding to the effective "load".

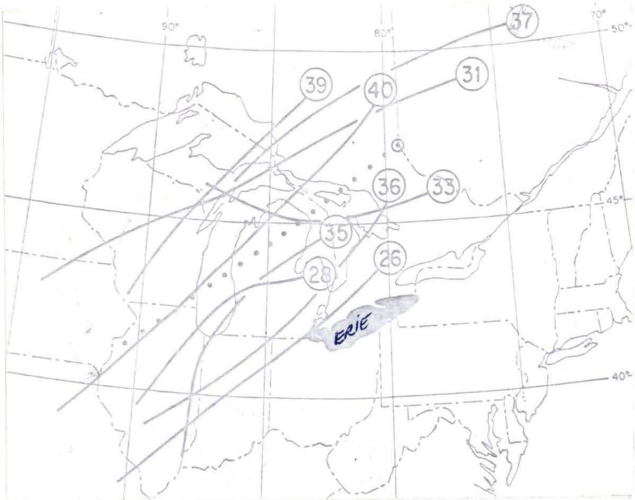


fig. 15 Paths of lows causing high wind tide conditions on Lake Erie. Circled numbers indicate position of low at the time of peak set-up (after Platzman, 1963).

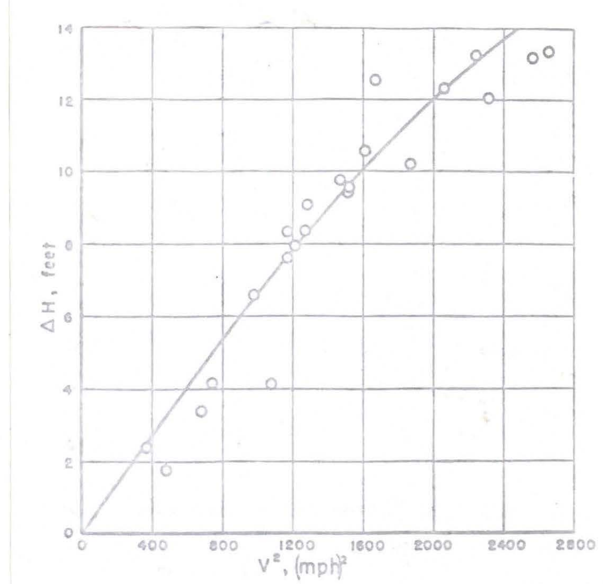


fig. 16 Graph showing relationship between height of wind tide and effective wind square (after Platzman, 1963).

Plate 11 A demonstration of wind transport of sand on Lake Erie beaches (photo Barnett, 1979).

Nourishment or depletion of beaches in this way may ultimately be a factor in bluff preservation or degradation since wide beaches provide essential energy buffer zones.

PRESSURE AND TEMPERATURE CHANGES

Although less significant and certainly less observable, fluctuations in air temperatures and pressure associated with storm passages have a direct bearing on shore processes. A temperature drop to below freezing will cause soils having sufficient water content to expand by the formation of ice. At a later time a thaw may occur that will permit contraction of the soil, allowing it to settle according to gravitational force. This process is termed creep by most geomorphologists and is illustrated in figure 17. In the Great Lakes region this type of movement would be more apt to occur in early or late winter and early spring when air and soil temperatures are most variable.

Seasonal temperature changes are important concerning Lake Erie because of the ease with which the lake surface freezes over. During the frozen conditions of the lake no waves or major erosion-causing disturbances generated, with the exception of some beach grading and ice push.

The onset of strong polar front invasions in the autumn will determine the time of ice formation on the lake in the winter. Likewise, early or late retreat of the front, in general, in the spring will dictate the time of surface thawing on the lake. Here again, Lake Erie is the most responsive of the Great Lakes. Figure 18 shows the extent of icing that occurs over the Great Lakes in a normal winter. Note that Lake Erie is all but entirely frozen over at the height of a normal winter.

A storm property perhaps less significant to lake processes than temperature changes is the pressure changes from the passage of storm systems. The strongest of these

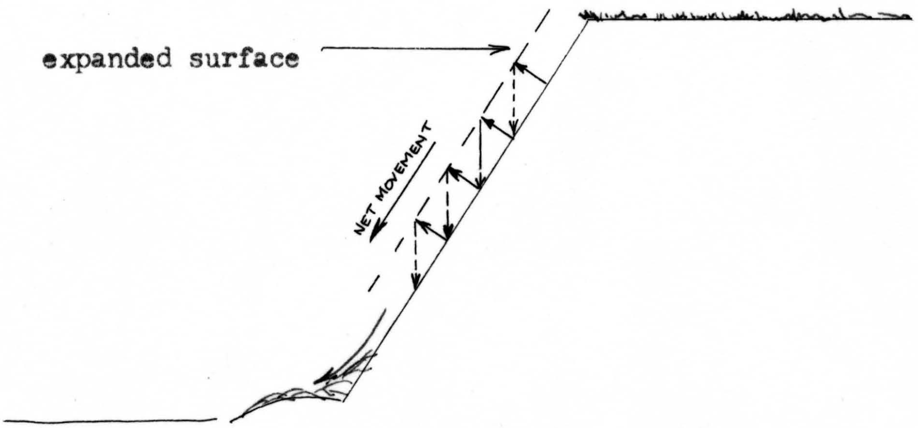


fig. 17 Movement of a soil particle during repeated freezing/thawing events on a slope. Solid arrows indicate motion of particle during freezing; dotted arrow describes the gravity return path of the particle after a thaw.

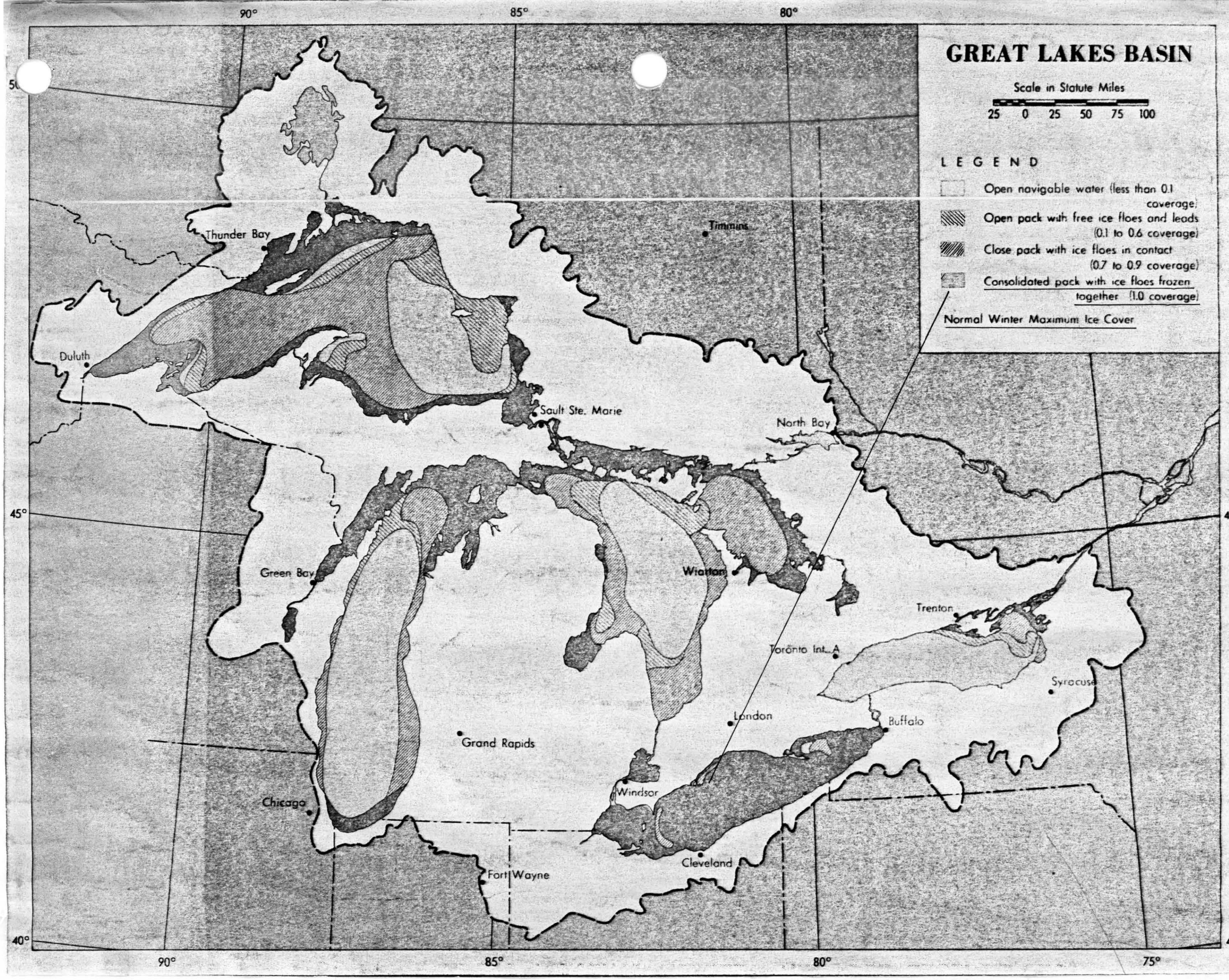


Fig. 18: During a normal winter Lake Erie experiences a more extensive ice coverage than any other of the Great Lakes. This may have valuable implications where shore erosion is concerned.

pressure fluctuations may be reflected in th local water level as a front or area of strong pressure gradient crosses the lake region. Verber, (1959) discusses short-term oscillations of lake levels and points out that 39% of noticable surges are due to barometric pressure changes. Some isolated occurrences have been cited concerning <u>pressure-jump</u> related waves or surges on the Great Lakes. D. Lee Harris, (1957), describes a situation that occured on Lake Michigan in June of 1954 in which a pressure-jump line associated with a fast-moving front apparently formed a resonant coupling with the water surface of the lake. The result of this was a single wave-like surge that ranged in height up to 8 feet and traveled across the southern portion of Lake Michigan. So sudden was the approach of the surge that 6 people drowned after being swept off a breakwater by the surge wave. Figure 19 is an isochrone analysis map of the pressure-jump line showing the path of travel with the front across the eastern U.S. It is not known how a pressure-jump of such magnitude would affect the nearshore areas of Lake Erie, but in view of how responsive Lake Erie is to such phenomena, a high assessment is in order.

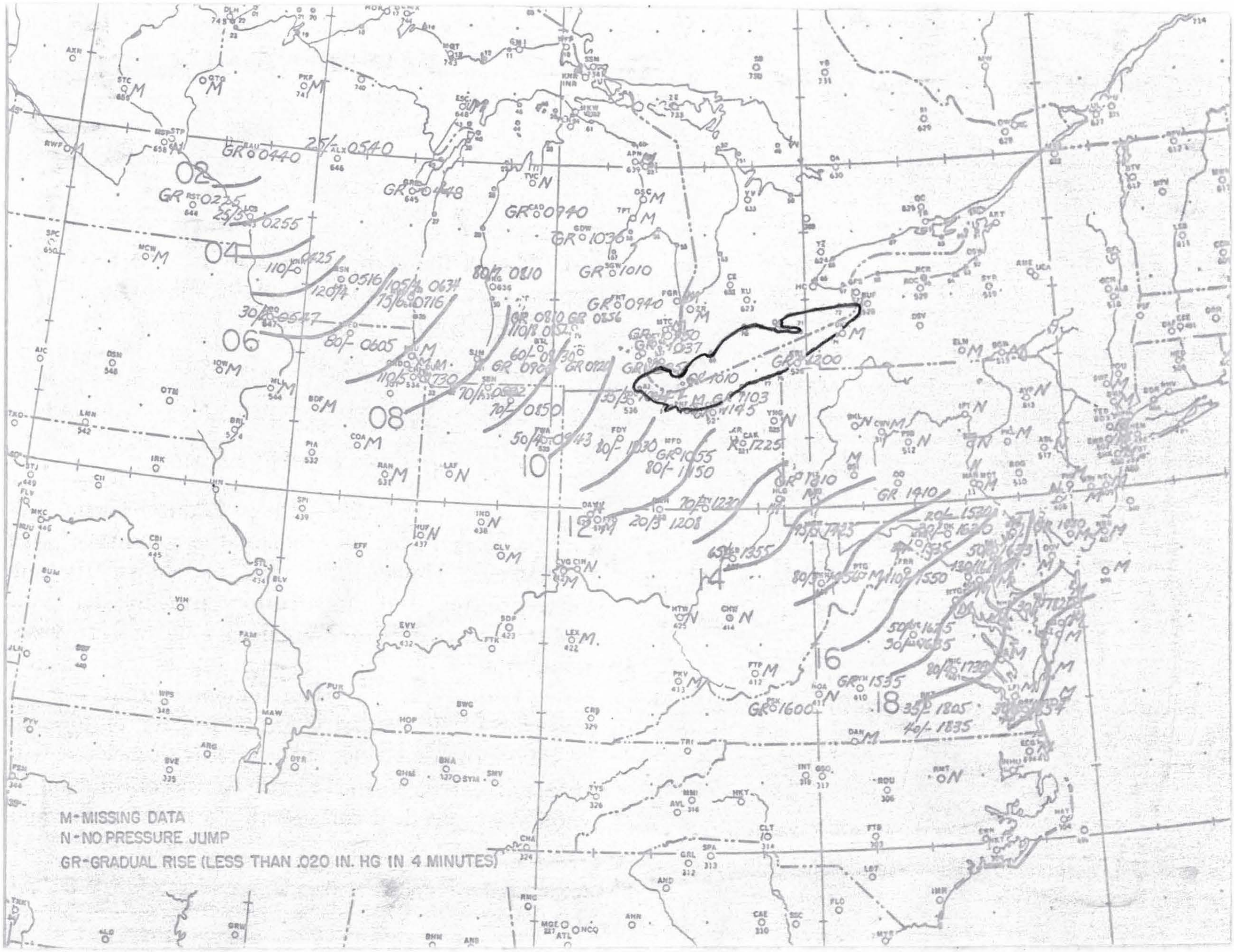


fig. 19 Path of pressure jump associated with a rapidly-moving cold front. To the left of the station circle is the ratio of total pressure rise (in 0.001 inches Hg) to duration of the rise in minutes. (After Hollyman, 1954)

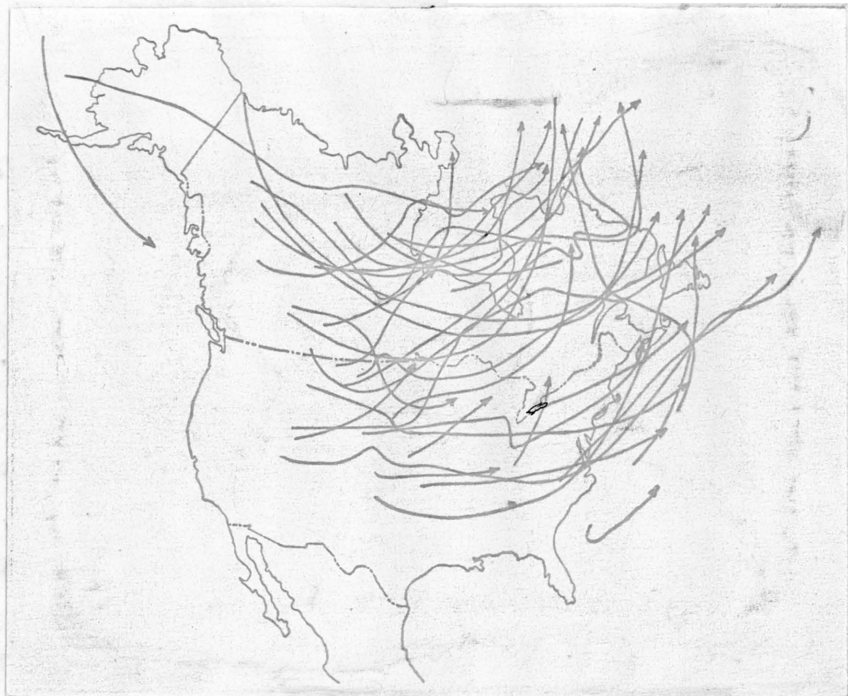
EXTRATROPICAL LOWS AS MAJOR DETERMINANTS OF EROSION

Though the topic of low pressure systems as erosion producers could consume several volumes, some basic essentials can be outlined within the scope of this report.

There seems to be two types of situations in which there is limited danger of active shore erosion of Lake Erie bluffs; those periods during which the lake is mostly frozen, and the brief interludes btween extratropical storm influences(High pressure dominance). During a normal winter Lake Erie is ice-covered from about the middle of January to the early part of March when the pack begins to decay. As said before, the seasonal ice mantle offers reprieve from vigorous erosion since it prevents the build-up of large waves, currents and oscillatory motions of the water normally associated with weather changes.

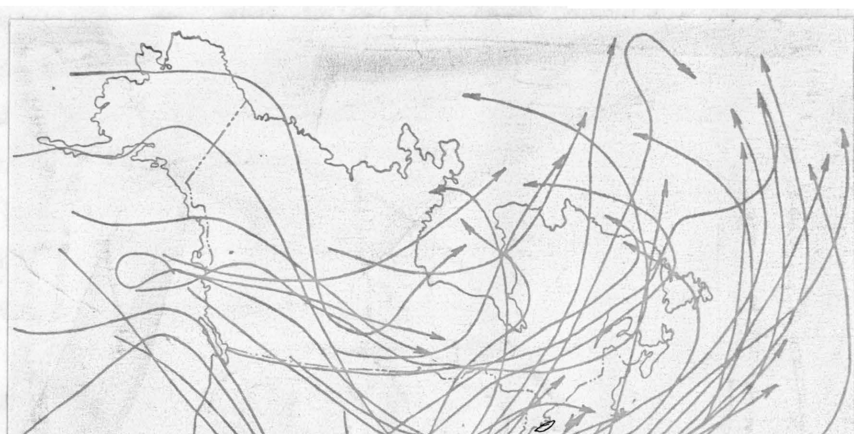
More important than ice cover are the number of energy events occurring on the lake throughout the year, most of which can be directly related to extratropical storm passage. It has been mentioned that these storms are closely tied with the behavior of the Polar Front and that the Polar Front itself will advance into or retreat from middle latitudes according to seasonal variations. Figure 20 shows the tracks of several noteworthy extratropical storms during the years 1938-1940. The paths of winter storms are shown in part (a) of figure 20 and summer paths in 20(b). Note the extent to which the winter storms dip into lower latitudes as compared to those in the summer.

It is possible to arrive at many important individual characteristics of these storms that have the greatest effects on the activity in the lake Erie region. The ones subsequently listed here are the points I feel should be considered most important where lakeshore erosion is concerned; 1. Air Mass characteristics and source regions; 2. Attitude of approach or TRACK; 3. Configuration of the storm system, and ; 4. the fig. 20



(b)

(After Foster, 1948)



(a)

intensity and duration of the storm. It can be said that most of these factors are interdependent, but assigning a specific weight of importance to each would be difficult.

There is not a great deal of conslusive information available on Air Mass and source region influences on storms of the Great Lakes area, but some correlations are offered by E.B. Garriot,(1903) concerning source regions. From data gathered over a period of 25 years on storm paths across the U.S. Garriot concluded that the most severe storms, in terms of gales and violent weather, originate in the Southwest U.S. and travel northeastward across the Great Lakes. Garriot also determined that November is the month of greatest frequency of severe storms over the Lakes.

As a LOW approaches an area ther will be an average "normal" sequence of events observed, depending on the direction of movement of the storm and what portion of the system is impinging on the area. Where the south shore of Lake Erie is concerned there are certain general tracks that lows may take and initiate high winds and waves. Figure 21 shows two storm patterns that were responsible for producing high winds and also probably high erosion rates on the south shore of Lake Erie. Earlier synoptic observations indicated that the storm shown in (b) of figure 21 was of southwest U.S. origin.

Once a low pressure system has begun to affect an area the total amount of energy released from the storm to the area considered will depend not only on the direction of of movement, but also the configuration of the system. Most extratropical lows have rainfall track patterns that are somewhat elliptical in form when plotted on isohyetal maps(maps plotting areas of equal precipitation). If a

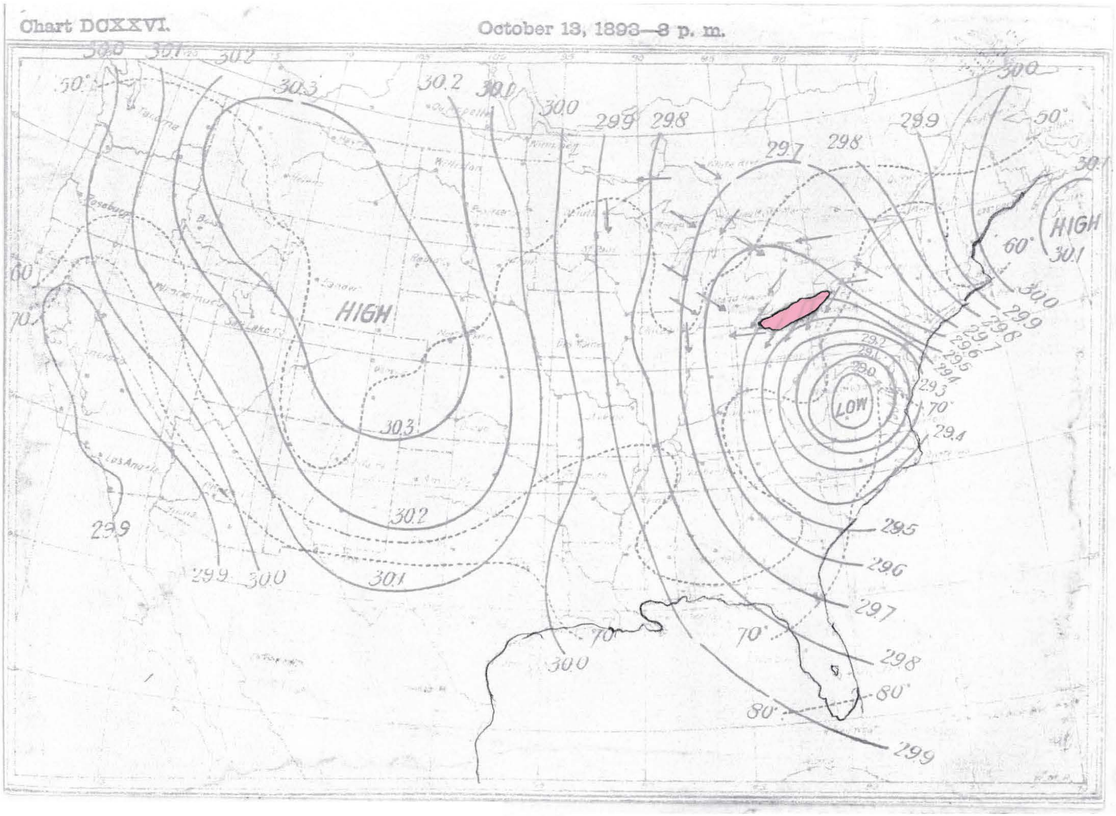
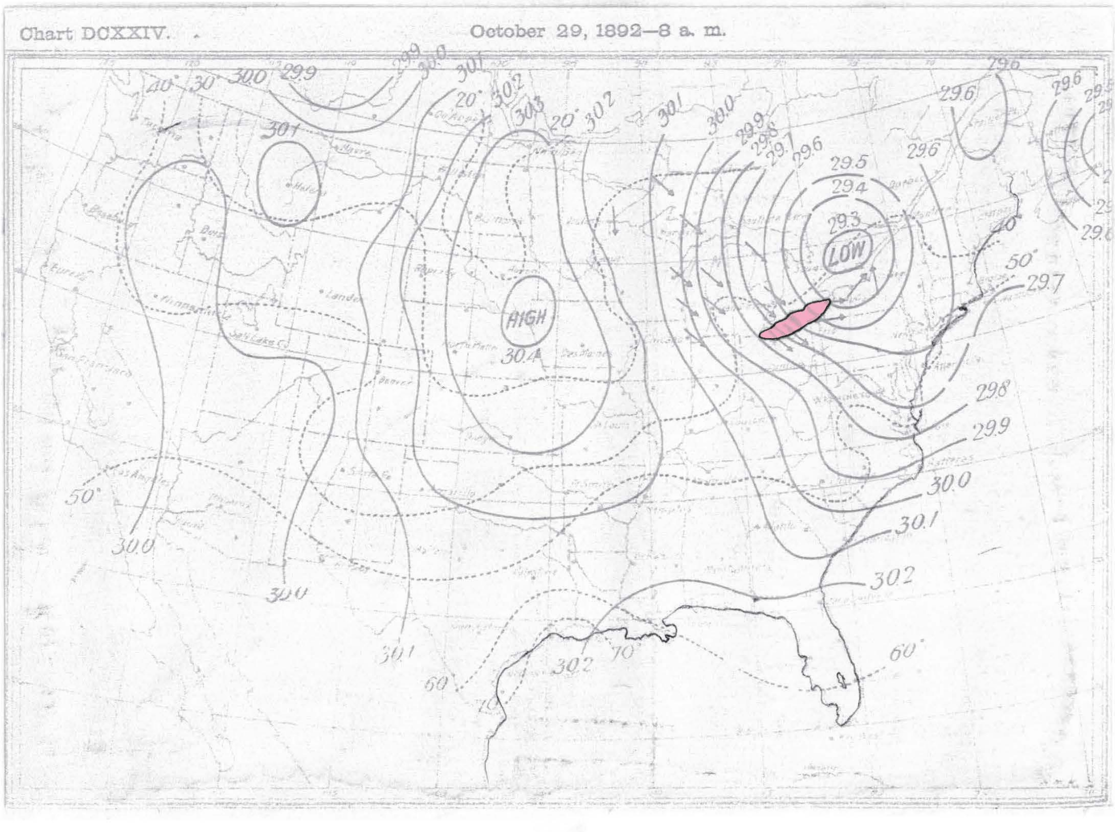


fig. 21
(After Garriott,
1903), Arrows
shown are wind
vectors.

(b)



(a)

line is drawn through the long dimension of these patterns a STORM AXIS can be constructed. Figure 22 illustrates a group of these axes from particularly severe storms over the years 1895 through 1937. It is interesting to see that although the majority of the axes shown in figure 22 terminate before reaching the Lake Erie region, there is still a hint of convergence of a great number of these axes on the area. Table 1 bears out the fact that Lake Erie along with Lake Ontario does indeed receive a greater amount of precipitation and supports the idea that a greater number of water-yielding storms invade the lower Great Lakes than adjacent regions annually. With this in mind, consider the fact that the Lake Erie basin occupies only 18% of the Great Lakes basin.

Edgar E. Foster, (1948), reiterates the conclusions of the U.S. Weather Bureau when he lists the types of general situations in which extratropical lows may produce intense periods of precipitation. These situations are briefly; 1. Thunderstorms in a north-moving tropical maritime air mass; 2. Decadent tropical hurricanes that have entered from the Gulf of Mexico; 3. Quasi-stationary or slow-moving fronts along which lows may progress; 4. Occlusion of a tongue of tropical maritime air; 5. Occlusion of deep extra-tropical cyclones and; 6. Rapidly-moving extratropical cyclones. (After Foster, 1948)

What is important here is that the Lake Erie basin is in the position to receive the effects of each of the aforementioned conditions and, hence, is apt to experience a wide variety of precipitation amounts over an extended period.

Fig. 22: Major storm axes of the eastern U.S. for the years 1895-1937. (after Foster 1948)

Mean monthly precipitation with indices of variation for selected months for the Great Lakes basins as calculated by the United States Corps of Engineers for 1931-1960

	January	April	July	October	Annual
ONTARIO					
Mean (Inches)	2.17	2.63	3.10	2.93	34.5
Standard Deviation (Inches)	1.04	.67	1.06	1.53	3.6
Coefficient Variation (%)	48	24	34	52	10
ERIE					
Mean (Inches)	2.54	3.14	3.06	2.64	33.8
Standard Deviation (Inches)	1.25	1.07	.89	1.48	4.7
Coefficient Variation (%)	49	34	29	56	14
HURON					
Mean (Inches)	2.40	2.43	2.78	2.87	32.0
Standard Deviation (Inches)	.61	75	71	1.36	3.2
Coefficient Variation (%)	25	31	26	47	10
MICHIGAN					
Mean (Inches)	1.81	2.70	2.99	2.57	31.5
Standard Deviation (Inches)	.62	1.05	1.06	1.43	3.4
Coefficient Variation (%)	34	39	35	56	11
SUPERIOR					
Mean (Inches)	2.06	2.18	3.08	2.55	30.9
Standard Deviation (Inches)	.67	.84	1.00	1.05	2.5
Coefficient Variation (%)	33	39	32	41	8

Table 1: precipitation amounts for the Great Lakes basins. (after Phillips and McCulloch, 1972)

TROPICAL STORMS

Though normally not deemed middle latitude phenomena, the effects produced by huge tropical disturbances (hurricanes) can occasionally be recognized as being significant to weather patterns over the Great Lakes region. Figure 11, page 33 shows the paths of some particularly severe hurricanes over a period of several years. Note that about half of these storms passed significantly near the Great Lakes region insofar as the effects of wind and precipitation would be concerned. Rainfall is usually torrential even during the degenerating stages of hurricanes as they pass over land, but the main concern on the Great Lakes are the strong and persistent winds accompanying the storm. Depending on size and rate of movement of the storm winds may blow at gale force for days, causing a great variety of set-ups, seiches, wind tides and waves, all conducive to heavy shore erosion.

Most commonly, the tropical storm will convert to an extratropical low and acquire many characteristics of the latter as it passes northward over land. As this happens, the remnant hurricane can interact with middle latitude frontal features and be temporarily sustained at a lower energy level by these, in terms of overall strength of wind , precipitation, etc. It is this interaction that may be watched for in order to make some sort of determination as to the conditions that could be initiated on the Great Lakes.

There are a multitude of factors which determine the strength, direction, duration, etc. of a storm system, such as upper air steering winds and jets, but the study of such subjects is still in a primordial state and further discussion of these would be mostly conjecture.

A very simple relationship between weather energies and Lake Erie shore erosion has been demonstrated. The most outstanding direct influence on shore erosion appears to be the extratropical low pressure system and elements associated with it. Intense thunderstorms and hurricane remnants are also pertinent factors to erosion, although not as numerous or significant as extratropical cyclones.

To this date, to the knowledge of the author, there has been no work done on the empirical relationships between selective weather phenomena and lake shore erosion. Charles Collinson, et al, (Coastal Geology, Sedimentology and Management, Chicago and Northshore, 1974), draw relationships between barometric pressure of passing cyclones, breaker height and longshore currents in Lake Michigan. They state; "Coastal processes along western Lake Michigan respond directly to low pressure systems that move in a generally west to east direction. Changes in the coastal processes, especially beaker height and direction of approach, and longshore current velocity and direction, are predictable, at least semi-quantitatively". This demonstrates an awareness of the relationships, but the subject is lending to much deeper investigation.

III. CHARACTERISTICS OF THE STUDY AREA

Location and Setting, Geology, and Manmade Influences

The shore area under study here is typical of the type of environments found in the Cleveland to Lorain section of the south shore of Lake Erie. Narrow beaches are backed by bluffs rising up to 70 to 80 feet in some places, and in many spots there are no beaches at all, even at low water times. At the Bay Village site however, there is a beach averaging about 26 feet in width that is frequently subject to submergence during high water events The bluff here is 25 to 40 feet high, with the greater height occurring at the eastern end of the area. The off-shore area is typified by a very shallow profile and a bottom consisting of shale/siltstone shingles nearshore with sand continuing offshore. A profile of this area may be examined in <u>Sedimentary Processes Along the Lake Erie Shore, From Four Miles East of Lorain, Lorain County, to Huntington Beach Park, Cuyahoga County, Ohio</u>, by Frank Kleinhampl, 1952.

The top of the study area bluff is the site of the Dover Bay Gun Club shooting range. To the east is the Bay Village Boat Club and Cahoon Park. Huntington Beach Park lies at the western extremity of the area, and as will be shown, has a profound influence on the condition of the study area shore.

Porter Creek enters the lake at the western edge of the study site and a small canyon exists here in conjunction with the stream (see appendix A). The presence of Porter Creek is important to the reach of shore to the east of its mouth because it supplies drift material for beach building. Kleinhampl, 1952, with regard to Porter Creek, states that the stream heads in an area of old beach terraces to the south and thus has access to nourishing sands.

Appendix C is a description of a typical section of bluff found at the study area. All of the outcrops found along this vicinity of shoreline are part of the Ohio Shale formation of Devonian age. The particular type of rock in the study area is, for the most part, designated as the Chagrin Shale member of the Ohio Shale. Except for the till-soil cap, the resistance of individual bluff components is quite variable. This, coupled with the fact that the lower components are alternately buried or exposed by variance of beach levels makes the construction of a weathered bluff section impractical. It may be mentioned though, that fortunately, the lower-most member of the study area bluff offers considerable resistance to wave and current erosion (refer to Appendix C).

It was mentioned that interests associated with Huntington Beach Park have considerable influence on the physical regime of the study area. This condition exists primarily because of the groin field constructed at the Park beach (see appendix B). Due to prevailing meteorological conditions the study area lies in the shadow of the groin field with respect to the littoral zone drift supply. The study area is deprived of much sand for its beaches because it is intercepted by the groins immediately to the west. Porter Creek, with its occasional supply of beach material to deliver, offers the only reprieve for this situation. Notice that the bluffs also reflect this availability of beach materials; the bluffs of Huntington Park are of fairly low repose and heavily vegetated, whereas the bluffs of the study area are nearly vertical in some places and have barren, active slopes (examine the air photos of appendix B stereoscopically).

Pl. 12 and 13 Porter Creek and the Porter Creek canyon area offer an important supply of sediment to study area to the east. The composite photo above was taken looking south from the water's edge; Porter Creek is at the far left. Note debris lines on the beach indicating varying water levels.

Left; a view of the mouth of Porter Creek during low flow.

Plate 14: A view looking west from the top of the bluff of the study area. Note the large tree (center) threatened by erosion of the bluff. Porter Creek and the Huntington groin field appear in the background.

Plate 15: View of the study area looking west from the Bay Boat Club jetty.

Plates 16&17 The vegetated, low-angle slopes of Huntington Beach (left) have become established primarily because of the great amount of beach material trapped by the groins constructed here. This is in contrast to study area (right), which has been deprived of sand because of the Huntington groins and thus suffers from a narrow beach and steep, active bluff slopes.

Plate 18 Toward the eastern extremity of the study area the supply of beach material has become entirely depleted, and due to currents generated by the jetty (upper left) the little material that reaches the area is swept offshore.

IV. BLUFF AND BEACH: Measurements and Observations

Since the time when the problems of shore activities have been recognized there have been many similar methods of ascertaining the amount of shore depletion or accretion over a period of time. The earliest attempts on classifying a shore in this respect merely involved the comparison of old photographs and/or paintings from different time periods. These are still a valuable source of information where other, more specific data are lacking.

It would seem that there are two main concerns involved with observing the evolution of a bluff shoreline, where measurable recession is of interest. The most apparent parameter may be simply the amount of retreat of the crest or top of the bluff with respect to a well-established landmark. In fact, aerial photos supply this information in very sufficient quantity and quality, such that it is probably the major means for evaluating this aspect of shore evolution and recession. The second consideration for bluff retreat observations is the evolution of the profile of the slope of the bluff. What is causing the failure of a particular bluff may not be readily evident from a horizontal examination, such as surficial geologic maps or air photos. Inspection of a vertical section of the area may provide information about undercutting or similar processes ultimately responsible for failure.

One of the preliminary measurements made of the bluff at the study area site was at the top of the bluff, adjacent to a steel chain-link fence bordering the Cahoon Park property. The poles of the fence are evenly spaced and are secured in the ground with poured concrete. The entire length of the fence approximately parallels the bluff line and seemed to provide an excellent ready-made reference system for observations of bluff top retreat. The results are presented in Appendix E.

At the base of the bluff 5 steel pins approximately 15 inches long each were driven in the side of the bluff at regularly spaced intervals of 100 feet. Appendix D lists the controls imposed on the driving of the pins. Appendix A also shows the positions of the pins with respect to the entire study area. These pins may prove useful if, at some later date, the dimensions tabulated in Appendix D are remeasured and compared to values listed here.

Direct inspection of the bluff slope was hampered somewhat because the nature of the materials composing it. A very thick, heavy clay originating near the top of the bluff covers most of its slope, especially in western sections (see plates 19 and 20).

Plate 19. Most of the bluff slope was covered with a very wet, heavy clay that tends to move down from a position near the top to accumulate on siltstone ledges found throughout the section.

Plate 20. Efforts to examine the members of the bluff at close range proved unfruitful due to the muddy condition of the slope.

CONCLUSION

The Bay Village study area is currently undergoing slight to moderate shore recession, and will continue to do so at a fairly uniform rate until the situation is interrupted by changing climatic conditions or the intergration of manmade influences. The bluffs of the study site are failing by mainly two means; the flowage or creep of clays, till and soil from the top, over the face of the bluff; and isolated block slumping of small jointed masses of shale that occur in the lower portion of the bluff.

The adjoining beach is composed of siltstone shingle in the western-most reaches, near Porter Creek, with the shingle becoming covered by a veneer of sand of varying thickness, progessively eastward.

The amount of sand coverage of the beach and the intensity of shore recession is determined primarily by the number and nature of extratropical lows that influence the area, versus the constructive influx of drift from nearby Porter Creek and the main nearshore littoral pattern.

As a useful recreational area the study site could be greatly improved by artificial nourishment with sand. The introduction of the sand coupled with the construction of a groin of modest length at a proper position in the area would afford a considerably greater degree of stability to both beach and bluff. It is my opinion that this action would not endanger any interests in the downdrift direction because of the placement of the Bay Boat Club jetty. However, the effects rendered by the occasional high-volume flow of Porter Creek would need to be considered in any improvement of the area.

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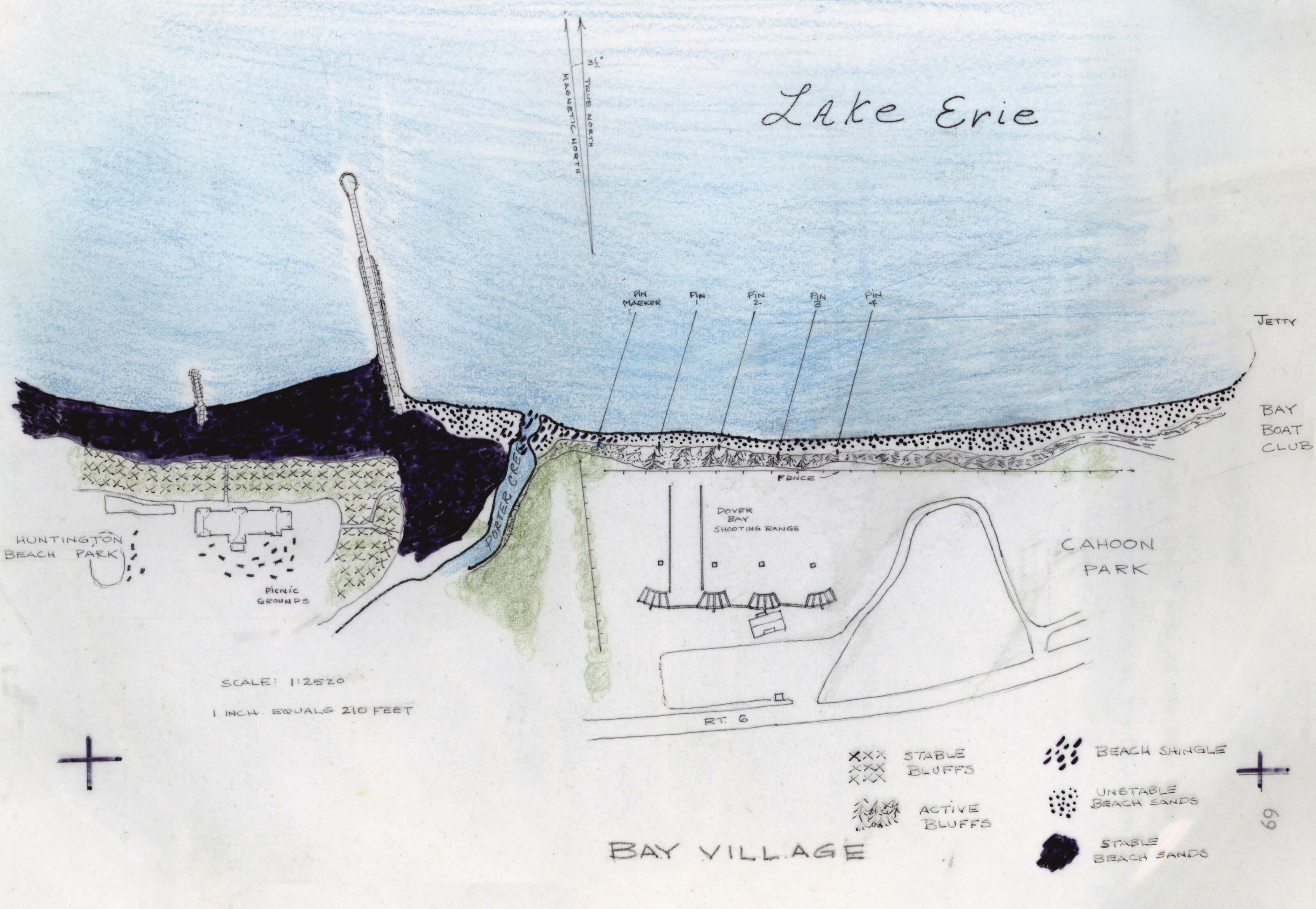
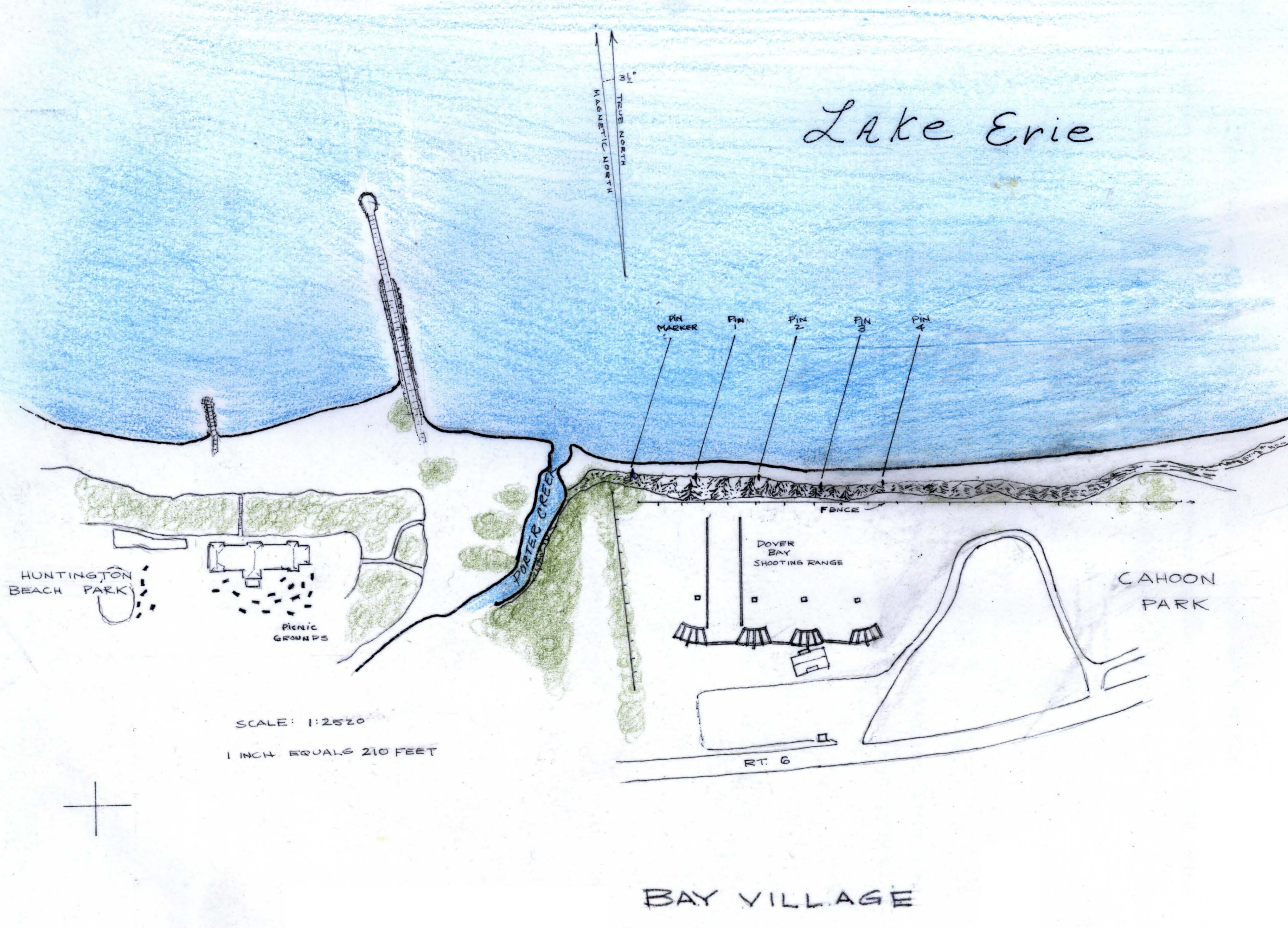
Appendix A - Map of the Study Area

This map was constructed from the aerial photos in part, and also from actual ground measurements conducted at the site. Some inaccuracy may arise from the fact that distortion occurs at the borders of the air photos due to perspective. The overlay was derived from data gathered by the direct general inspection of the area and represents prevailing conditions in August of 1979.

Unstable materials indicated on the overlay are those having a relatively short residence time.


Lake Erie
TRUE NORTH
MAGNETIC NORTH
3½°
JETTY
BAY
BOAT
CLUB
PIN MARKER
PIN 1
PIN 2
PIN 3
PIN 4
FENCE
PORTER CREEK
DOVER BAY
SHOOTING RANGE
CAHOON
PARK
HUNTINGTON
BEACH PARK
PICNIC
GROUNDS
RT. 6
SCALE: 1:2520
1 INCH EQUALS 210 FEET
STABLE
BLUFFS
ACTIVE
BLUFFS
BEACH SHINGLE
UNSTABLE
BEACH SANDS
STABLE
BEACH SANDS
BAY VILLAGE


Lake Erie
TRUE NORTH
MAGNETIC NORTH
3½°
PIN MARKER
PIN 1
PIN 2
PIN 3
PIN 4
JETTY
BAY BOAT CLUB
FENCE
PORTER CREEK
DOVER BAY SHOOTING RANGE
CAHOON PARK
HUNTINGTON BEACH PARK
PICNIC GROUNDS
RT. 6
SCALE: 1:2520
1 INCH EQUALS 210 FEET
BAY VILLAGE

Appendix B - Air Photos

These air photographs of the Huntington Beach area of the Lake Erie shore were obtained from the Aerial Engineering Division of the Ohio Dept. of Transportation. They are presented as follows:

1-a and 1-b ; March, 1968

2-a and 2-b ; April, 1973

3-a and 3-b ; June, 1974

Photos dating back even earlier may be obtained from the Ohio Department of Agriculture at a somewhat immodest price.


3881-16-425
1-a


3881-16-926
1-b

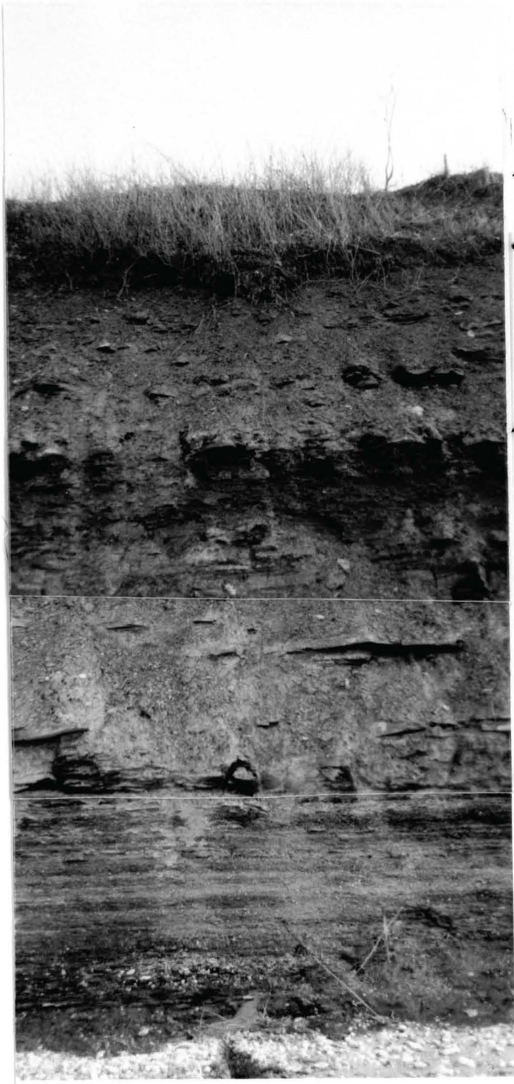

5196-12-418
2-a


5196-12-419
2-b


3-a

4 9
3-b
S462-20-427

Appendix C - Bluff Section



top

type of material exposed *	approximate thickness of exposed section (in feet)
Glacial till and soil cap	5
Dark gray clayey shale interbedded with siltstone in some sections	5
Blue-gray shale with resistant siltstone ledges	7
Fairly resistant blue-gray to black shales	5
	total; 22 feet

* with reference to Frank Kleinhampl, 1952

beach

A typical section of bluff at the Bay village study area. The bluff increases considerably in height to the east, apparently due to the emergence of the lower shale member near beach level as well as increased thickness of the clayey shale directly below the soil-till cap. The section presented here occurs near pin No. 2.

PIN NO.	HEIGHT OF PIN ABOVE BEACH LEVEL	LENGTH OF PIN PROTRUDING FROM BLUFF	DISTANCE FROM MARKER PIN	WIDTH OF BEACH - COMMENTS
Marker	5 ft.	14 cm	---	33 ft. - Beach consists of shingles near toe of bluff.
1	5' 3"	9 cm	100 ft.	30 ft.
2	5' 8"	11.5 cm	200 ft.	29 ft.
3	5' 5"	11 cm	300 ft.	26 ft.
4	5' 8"	21 cm	400 ft.	13 ft. - Overhanging clayey siltstone ledges show sole markings or load casts.

Five steel pins were driven into the face of the bluff near the base in order to permit the possibility of measuring the amount bluff recession at a later date. Pins were not placed in the eastern portion of the bluff due to the well-consolidated nature of the bluff materials in this area. There is a general decrease in the width of the beach progressively to the east as the above table reflects and at the eastern extremity the beach disappears completely at one point (examine air photos sets 2 and 3).

It is suggested that any further work involving the pins be done fairly soon. The pins are not embedded in the bluff to a great degree and failure of the sort indicated in plate 7 may cause the pins to become dislodged from the bluff in one brief erosion event.

Appendix E - Bluff Fence Measurements

FENCE POST NO. (AS MEASURED FROM WEST END OF FENCE)	DISTANCE OF FENCE FROM EDGE OF BLUFF
NO. 8	11 ft.
12	0
15	13
21	12
28	12
30	5
33	3
34	2
37	4.5
39	12
43	13
45	5
49	12
54	6

Average dist. = 8.5 ft.

Max. = 13

Min = 0

The fence approximately paralelling the top of the bluff provided a convenient reference system for detecting bluff-top retreat. The variability of the distances of the fence from the bluff edge is mainly due to the occurrence of large drainage features at various intervals along the bluff. The measurements were stopped at post 54 because of obstructing vegetation.